PRODUCTION ORDER-BASED MANUFACTURING: A CASE STUDY ON THE EFFECT OF PRODUCTION PLANNING AND SCHEDULING SYSTEMS IN ENHANCING PRODUCTION EFFICIENCY

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ABSTRACT

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Production order-based manufacturing: A case study on the effect of production planning and scheduling systems in enhancing production efficiency

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Keywords: production planning, Material Requirements Planning (MRP), lean manufacturing, ERP systems, SAP, planning methods, production orders

In this study, a pilot project was carried out evaluating the ability and impact of transitioning from a prior way of executing the production planning process in SAP Production System (PS) module to a unified method of using SAP Production Planning (PP). PP is implemented on smaller-scale manufacturing at this specific plant. The focus of this study is on a specific manufacturing plant producing industrial filtration systems and modernizations, with a need for a unified method of executing planning to achieve efficiency regarding the manufacturing process.

The PP module is used to form production orders for assemblies which has not previously been adopted for projects at this specific plant. This method has been utilized in smaller scale manufacturing such as in-house own component manufacturing and spare part assemblies. This project involved creating the material data for the main assemblies and several subcomponents, routings, costings as well as forming production orders based on the scheduling data created in Project Builder on SAP.

Results are limited to one project for which broader implementation and further research are recommended to validate the general applicability and long-term outcomes. However, results indicate that unifying production planning under one module in SAP for all manufacturing at this specific plant can enhance process consistency throughout, especially at an operational level and benefit the overall efficiency of project management. Additional benefits can include real-time monitoring of production processes with proper tools and training.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

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Konetekniikka

Olivia Kuusman

Tuotantotilauspohjainen valmistus: Tutkimus tuotannonsuunnittelun ja aikataulujärjestelmien vaikutuksesta tuotannon tehokkuuden tehostamiseen

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Tutkimus koostuu pilottiprojektista, jossa arvioitiin tuotannonsuunnittelun yhtenäistämistä siirtymällä projektien aikaisemmasta toteutustavasta SAP Project System (PS) moduulista yhtenäiseen suunnittelumenetelmään SAP Production Planning (PP) moduuliin. PP moduulia hyödynnetään kyseisellä tuotantolokaatiolla pienemmän mittakaavan valmistuksessa, kuten varaosakokoonpanoissa ja komponenttien valmistuksessa. Tutkimuksen kohteena on teollisia suodattimia valmistava tuotantolokaatio, jossa on havaittu tarve yhtenäiselle suunnittelumetodille tuotantoprosessien tehostamiseksi.

Pilottiprojektin aikana PP moduulia hyödynnettiin tuotantotilausten ”Production Orders” muodostamiseen projektin kokoonpanoille. Kyseistä menetelmää ei ole aikaisemmin implementoitu kyseisellä tuotantolokaatiolla. Menetelmää kuitenkin hyödynnetään pienimuotoisessa valmistuksessa, kuten valmistettavien komponenttien ja varaosakokoonpanojen tuotannossa. Projektin aikana muodostettiin materiaalitiedot pääkokoonpanoille ja useille alanimikkeille, työvaiheiden kestot ”routing” avulla, kustannuslaskelmat kokoonpanoille sekä tuotantonumerot Project Builderissä laaditun aikataulun pohjalta.

Tulokset rajoittuvat yhteen projektiin, minkä vuoksi laajempaa käyttöönottoa ja lisätutkimusta suositellaan yleistettävyyden ja pitkän aikavälin vaikutusten seuraamiseksi. Tulokset kuitenkin viittaavat siihen, että tuotannonsuunnittelun yhtenäistäminen SAP:n yhden moduulin alle kyseisellä tehtaalla voi vaikuttaa positiivisesti prosessien johdonmukaisuuteen erityisesti operatiivisella tasolla ja edistää projektin hallintaa kokonaisvaltaisesti. Lisäetuina on mahdollisuus reaaliaikaiseen tuotantoprosessien seurantaan hyödyntämällä oikeita työkaluja ja koulutuksen avulla.

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SYMBOLS AND ABBREVIATIONS

Symbols

L_{max}	Maximum lateness
n	Sample size
r_j	Release time

Abbreviations

AI	Artificial Intelligence
APP	Aggregate Production Planning
DPS	Detailed Production Schedule
DS	Detailed Scheduling
E	Procurement type – In-House Production
E50	Procurement type – In-House Production (phantom)
ERP	Enterprise Resource Planning software
F	Procurement type – External Procurement
FICO	Financial Accounting and Controlling
GR	Goods Receipt
HANA	High-Speed Analytical Appliance
ISO	International Organization for Standardization
JIT	Just-In-Time
KPI	Key Performance Indicators
LM	Lean manufacturing
MM	Material Management

MPS	Master Production Scheduling
MRP	Material Requirements Planning
MTO	Make-to-order
MTS	Make-to-stock
PDS	production data structure
PF	Pressure Filter
PIR	Planned Independent Requirement
PLM	Product Lifecycle Management
PldOrd	Planned Order
PM	Plant Maintenance
POitem	Purchase order
PP	Production Planning
PP/DS	Production Planning and Detailed Scheduling
PPS	Production Planning and Scheduling
PrdOrd	Production Order
ProjSt	Project Stock
PS	Project System
QM	Quality Management
QMS	Quality Managements Systems
S&OP	Sales and Operations Planning
SAP	System Analysis Program Development
SD	Sales and Distribution
ShpgNt	Shipping purchase order
SMED	Single Minute Exchange of Die

TPS	Toyota Production System
VMI	Vendor-managed inventory
WBS	Work Breakdown Structures
WIP	Work-In-Progress

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1 Introduction

Production planning is a key aspect of any manufacturing process, as it serves as the foundation for organizing production steps, optimizing resource allocation, and managing schedules to meet production objectives. Production planning efficiency directly impacts delivery times, productivity and overall operational performance. This study focuses on the key components influencing production planning efficiency by unifying production planning methods to production order-based production. By exploring potential bottlenecks and opportunities for process optimization, this study aims to enhance production planning methods and outcomes.

Production order-based manufacturing involves assigning tasks to specific resources such as machines or work centres. The objective of this is to specify the sequence of actions required at each phase of production and how long each step account for. Common challenges regarding production planning and scheduling arise due to process flow constraints, capacity planning and resource availability constraints such as material shortages, workforce limitations as well as production bottlenecks. These may lead to longer lead times, unattainable delivery dates, reduced productivity and inefficient production.

Project-based manufacturing can be managed through SAP Project System (PS) module, which has been created for managing large, complex projects with detailed work breakdown structures and resource management. However, as production processes evolve a shift towards using SAP Production Planning (PP) module for managing project-related production planning can be more apparent. This transition is done based on the need to integrated project planning more closely with manufacturing, providing an efficient flow of information across the whole production lifecycle. The use of PP module can increase efficiency and provide real-time monitoring within SAP regarding different production phases. This can enable improved visibility throughout the process, faster response time to changes, and efficient coordination between teams. This supports proactive decision-making and enables the integration of different monitoring tools in SAP such as capacity planning, production planning and production order progress tracking.

1.1 Background and motivation

The company in question, which this thesis is conducted for is a global organization with robust presence is the industrial and environmental sectors providing cutting-edge equipment, technology and services. The company is well-known for providing sustainable and efficient solutions which enhance productivity while having a focus on minimizing environmental load. The global reach of this company allows catering towards a broad range of customers, providing tailored solutions designed to meet the specific needs of different requirements in various industrial sectors. This company is well known for producing high quality products.

The focus of this research is on a specific manufacturing plant which produces substantial projects ranging from smaller to larger sized filters, spare parts and modernizations to fit the needs of different applications in the mining industry and in other industrial processes. This study is based on the goals and objectives of this company with the need for a cohesive production planning method which can be implemented on all production related tasks. This is done to enhance productivity and to streamline operations. Production planning at an operational level builds a foundation for all phases of production by establishing criteria. The output of planning and methods can be decided upon the organization and different methods can be implemented based on the criteria outlined inside the organization based on the company's values.

The motivation for this study is based on the need to unify production planning by transferring all planning processes into the PP module at this specific plant. This includes project-based production which has yet to be implemented. A standardized system reduces complexity and streamlines the overall planning process. Integrating all planning functions under one module, the PP module, can enhance reporting accuracy, reduce the risk of discrepancies and improve the communication between teams. This study evaluates the effectiveness and challenges caused by transitioning to a unified planning process and provides insight to support the decision-making process for optimizing production planning on SAP.

1.2 Research problem and questions

The aim of this study is to answer the following research questions where question one is the focus of this study. These research questions are formed to give insight into the complexity of configuration and data integration in SAP as well as the application of gathering data to its full potential in different SAP modules. Questions “a” to “c” are sub questions related to the main research problem:

1. What are the key factors impacting the accuracy and efficiency of production scheduling in SAP S/4HANA Production Planning (PP) module?

    a. What are the effects on production planning efficiency when unifying production planning methods?
    b. How does production order-based manufacturing effect cross-functional coordination and how is it interlinked?
    c. How is production efficiency measured and what methods could be utilized in the future?

These research questions outline the core of this study and are used to identify the impact of data integration between SAP modules and relevant data in production planning. By analyzing these questions, the study aims to provide valuable insight into the optimization of production planning in SAP.

1.3 Objectives and limitations

The objective of this study is to conduct a case study on the unification of production planning, examining the impact of integrating production-order based manufacturing on larger scale projects with more complex structures. Through the pilot project this study will underline the functionality of merging all production planning to a production-order based system in SAP Production Planning module. A detailed analysis of the PP module is presented in Chapter 3.3 SAP Production Planning. This study covers recommendations and

potential long term improvement suggestions as well as opportunities though findings in the piloting phase.

The current way of production planning at this specific plant is done using two modules within SAP called Project System (PS) and Production Planning (PP). Currently, PS is mainly used for managing projects, while PP is used for handling spare part and in-house own component manufacturing. The use of two methods of production planning results in inefficiencies and challenges in coordination, as production planning is divided between these two methodologies. Having two methods which differ, means that there are two ways of executing different tasks. This reflects and influences different phases of production. An example of this is regarding the operational level where picking and assemblies are done using two different methods, leading to variations in efficient and process consistency.

Limitation is apparent due to this version of SAP being new to this plant, with further changes and advancements being implemented gradually. Additionally, not all tools are available for said plant which limits the focus on integrating additional monitoring or planning tools. However, these can be explored at a theoretical level. Limitations include the piloting phase of this study which accounts for one project. Therefore, the findings provide good insight into the process but due to the solitary of this case study, results imply general results. Hence, the limitations account for the need to conduct similar studies on various cases to achieve a more generic conclusion on the overall results.

1.4 Research methodologies

This research combines qualitative and quantitative approaches integrating a comprehensive literature review on production planning in SAP, production planning pilot project and the consultations of experts in various fields. These methods are chosen based on the need to combine theoretical and practical aspects of production planning. By using multiple different research approaches, this study gives insight in diverse perspectives, ensuring a comprehensive understanding of the research topic. The literature review forms the foundation for this thesis, providing a systematic overview of the theories applied in the pilot project, as well as a review of previous research and relevant applications. The pilot project aims to provide an initial test of the theoretical concepts researched in the literature review by applying it to a real-word scenario of production planning in SAP.

To ensure the reliability and validity of this study resent peer reviewed articles which are published mainly between 2020-2025 are used. In addition, literature such as books, conference readings and well cited articles are used to ensure the validity. Other sources outside the published literature include consultations with professionals and a case study, the pilot project.

1.5 Outline of the thesis

This thesis is divided into a literature review, a pilot project and summary on previous research on this topic as well as an overview of the pilot project results and conclusions. The structure of this thesis is assembled by building a foundation through a literature review which includes chapter 2 regarding production planning. This chapter gives insight into factors such as effectiveness and how it can be measured, methods which can be implemented during planning. Chapter 3 goes in depth into production planning in SAP concentrating on modules which were used in the pilot project. Chapter 4 is the methods phase of this study where the pilot project is discuses and how it is formed. Results are introduced in chapter 5 and are discussed further in chapter 6. The results of this thesis are based on a review of production planning in SAP S/4HANA Production Planning (PP) module. The conclusion of this study is in chapter 7.

2 Key concepts in production planning

This chapter provides a review of different methods used in production planning. In addition, a literature review of relevant findings related to this study are analysed focusing on different production planning methods. These include the framework of production planning and what factors make scheduling amongst various stages effective in addition to methods which can be implemented during scheduling. This literature review is used to lay the groundwork for the pilot project in chapter 4 where findings are applied to an existing project.

2.1 Objectives of production planning and scheduling

In manufacturing, production planning has a key role in decision making processes where production planners determine methods required to achieve effective production schedules (Tenhiälä 2011, 65; Zanella & Vaz 2023, 823-824). Production planning consists of several aspects including production requests, production orders, production scheduling and inventory management. The main factors which must be accounted for while planning are material requirements and capacity. Material requirements are determined based on the product's bill of materials (BOM). While planning the production, the capacity and production requirements must be considered. Material requirements planning (MRP) perform the foundation of production planning and ensures the availability of resources. (Sarferaz 2018, 154-155.)

Implementing a production scheduling plan based on the complexity and needs of the manufacturing phases can affect the production cycle by improving the competitiveness of an enterprise and lead to an increase in economic benefits (Zhang, Li, Kan, Zhang, & Li 2021, 579). Effective production planning refers to the optimization of the process determining an efficient way of allocating resources, scheduling tasks while achieving set goals. The complexity of production planning is determined by the number of variable and parameters. Systems with a lower number of parameters are easier to navigate compared to systems with more parameters. (Jodlbauer & Strasser 2019, 2.) Variables in production planning refers to elements which can change whilst parameters are fixed values and constraints that do not change.

Scheduling is a crucial part of any production process where tasks or jobs are assigned to a specific objective criterion and can be defined as the assignment of requests such as tasks or jobs to available resources over time. The focus of this is to determine what needs to be executed at each phase and how long these steps account for. Scheduling problems are often defined by three distinct components which include tasks to be completed, resource availability and the objectives as well as criteria for determining the optimal solution. (Chinos & Vakhania 2017, 2-3.) The number of machines and steps in production affect the complexity of planning where systems with multiple machines or steps require more attention to planning regarding systems with lesser number of variables. Various ways of conducting scheduling have been studied in literature broadly and the optimization of this. The main part of scheduling has been classified in previous literature as arranging tasks and resources in a balanced matter. (Tokola, Niemi, & Kyrenius 2017, 172.)

Early decisions made in the pre-scheduling phase such as the allocation of resources, raw materials and time constraints, defines the scheduling approach by establishing the framework. The initial decisions in the pre-scheduling phase directly impact the efficiency and flexibility of production schedules. This framework defines how tasks are prioritized and how resources are allocated. (Chinos & Vakhania 2017, 2-3.)

Rescheduling is often a part of production planning when a new unexpected variable occurs affecting the initial schedule. One instance which can cause alterations to planned or ongoing schedules is customer orders with a high priority or machine breakdowns. The effect of rescheduling should be analyzed and thoroughly planned so that it does not affect other orders and production phases. In addition to how rescheduling should be executed, the knowledge of when the scheduling should take place is beneficial. There are different ways of executing rescheduling where the whole schedule can be reorganized, or only selected steps of the schedule can be rearranged. Production planning methods which are executed in a poor way led to issues related to the lead time of the product for example excessive lead times or tight schedules. Tight schedules which are not attainable lead to failures regarding the delivery dates. (Tokola, Ahlroth, & Niemi 2014, 165-166, 169-171.)

Effective planning can be determined by material management as well which is a critical aspect of any production processes. Material management determines the whole production phase and is a critical factor throughout the whole supply chain. This determines when materials are required for each production phase and an increase in expenses can occur if

there are discrepancies in material availability. In addition, the unavailability of materials may affect the overall schedule and result in delays. (Rivera-Gomez, Sanchez-Partida, Ortega-Reyes, & Gonzalez-Hernandez 2024, 281.) To achieve effective production, critical issues, need to be addressed such as reducing production costs, improving production capacity and making production cycles more efficient. These can be achieved by adapting optimal production planning determined by implementing scheduling techniques and ensuring a balanced workload across each production phase. (Zhang et al. 2021, 577.)

Additionally, there are standards which can be implemented with planning such as ISO 9001:2015 Quality management systems requirements section 8.1 Operational planning and control, which covers the need to meet the requirements of the overall process. ISO 9001:2015, the international standard for Quality Managements Systems (QMS) is used to establish effective processes for optimal quality management and meeting customer demands. Section 8 is centered on “Operation” focusing on processes organizations must implement to achieve optimal performance while catering to the customer demands. Under section 8. Operation is 8.1 Operational planning and control which is used to ensure that organizations plan processes satisfactorily and control them effectively. The organization’s operations must be planned, executed and controlled throughout the whole process by establishing criteria for the overall process from planning necessary resources, processes and responsibilities. (SFS-EN ISO 9001, 2024.)

2.2 Production planning approaches

Planning approaches are based on demand and supply strategies which include make-to-stock (MTS), make-to-order (MTO), assemble-to-order, and engineer-to-order (ETO) manufacturing. MTS planning is a straightforward planning approach where materials are produced based on forecast. This type of manufacturing ensures efficient maximisation of resources in production and provides the fast delivery times compared to the other strategies mentioned. (Weber 2018 13-14; Goel 2022, 38). MTO and ETO are most often used in project-orientated planning where products are customized to meet customer requirements. (Carvalho, Oliveira, & Scavarda 2015, 188.)

Disadvantages in MTS production includes the risk of over-production resulting in increased inventory levels and inventory costs (Weber 2018, 13; Ghasemi, Lehoux, & Rönnqvist,

2024, 1). MTO approach is used when products are produced only on customer requests and purchases. This approach is typically longer than the MTS approach since products in MTO are produced on demand. The lead times for MTO are determined on the number of raw materials stored and what need to be sourced. To gain shorter lead times the production must be flexible to meet customer requests. An advantage in this type of production is that the risk of excess stock is minimized. (Weber 2018, 14.)

Often companies opt to adopt a hybrid manufacturing approach where multiple production methods are integrated to cater to a broader customer base while improving service reliability. By adopting multiple approaches manufacturers can balance the benefits of these production approaches. The benefits may include such as mass production for cost efficiency and customization for meeting specific client demands. As a result, hybrid manufacturers are better equipped to navigate market fluctuations and sustain an advantage in the market. (Ghasemi et al. 2024, 1-2.)

Ghasemi et al. 2024 conducted a study on a mixed production-inventory system in a multi-level supply chain utilizing MTS, MTO and vendor-managed inventory (VMI) strategies. Vendor-managed inventory is a strategy in which the supplier takes responsibility for managing the customers inventory. This study emphasises the importance of production planning in maintaining service levels for different customer segments. To address the challenges related to fluctuating demand and strategy coordination, the authors used a rolling horizon planning approach. This study highlights the impact of key parameters on strategy allocation and emphasises the influence of sales prices on customer distribution across different approaches.

Production planning in a hybrid production can be challenging in different ways due to distinct planning and control requirements as well as the different decision-making processes for MTO and MTS. The basis of these approaches differs significantly. In MTO production planning materials must be manufactured accordance to predetermined due dates focusing on scheduling and sequencing operations. MTS production planning is centred around preventing stock-outs, minimizing inventory costs and planning decisions are usually cost-based. (Beemsterboer, Land, & Teunter 2016, 453.)

Beemsterboer et al. 2016 conducted a study on the benefits of a hybrid planning method based on a modelling approach where discrete-time Markov Decision Process is used to

analysed which products MTO or MTS should be produced at given time. Markov Decision Process is a mathematical decision-making process with dynamic optimization problems. The first appearance of this theory was formulated in 1950's by Richard Bellman. Since the formulation of this theory, it has developed substantially. This model is used in situation where outcomes are random or partially random and actions are based on current situations to get the optimal solution in the long run. (Bäuerle & Jaśkiewicz 2024, 141-142.)

In the Beemsterboer et al. 2016 study two policies were highlighted: MTO priority and MTS priority. When MTO products become available for manufacturing MTO priority takes effect. Whereas priority is given to MTS products as soon as inventory levels become lower than defined. MTS priority is independent of MTO and is defined as a predetermined fixed switching level. A fixed switching level refers to a specific point set in advance in decision making, triggering actions within a system based on a mathematical model or algorithm. The comparison of optimal switching levels amongst the policies is essential to find the optimal switching level for the pre-determined priorities. The study concluded that when there are little to no MTO orders, production capacity should be used to build up stock for future demand. If MTO orders are present, fulfilling these orders may take priority over building up stock and fulfilling MTS production.

Planning can be done based on time-phased planning such as material requirements planning (MRP) or rule-based methods such as just-in-time (JIT) manufacturing. Time-phased planning such as MRP is particularly effective in MTO production. Whereas JIT techniques more suited for MTS production and thus used in these instances. (Tenhiälä 2011, 66.)

ETO is used in instances where customized products are manufactured and delivered to a customer. Production flow and capacity is based on the volume of customer orders. ETO production consists of physical and nonphysical stages where physical stages are classified as the assembly phases and component manufacturing. Nonphysical stages involve process optimization, planning and engineering to meet customer needs for customizations. (Carvalho et al. 2015, 187.)

Assemble-to-order (ATO) is a combination of MTO and MTS where parts of the product are pre-manufactured but not fully assembled. This enables for partial customizations for customers' orders and fast assembly leading to shorter lead times compared to MTO. When an order is received, components are assembled to complete the final product. This is known

as a hybrid production planning and control approach. Advancements with enterprise resource planning (ERP) software enable improved tracking and documentation of production activities. (Celik & Yurtav 2025, 23866-23867.) Both time-phased planning and rule-based manufacturing is apparent in ATO (Tenhiälä 2011, 66).

2.3 Production planning methods

Production planning methods can be categorized based on the range of the planning phase as seen in Figure 1. Long-range planning phases include product engineering, medium-range planning involves aggregate planning and short-range planning such as production scheduling planning at an operational level (Jamalnia, Yang, Feili, Xu & Jamali 2019, 159-160; Zanella & Vaz 2023, 1.)

Aggregate production planning (APP) is a medium-range planning with a timeframe of 3 to 18 months. (Jamalnia et al. 2019, 159-160; Carvalho et al. 2015, 188.) The objective of APP is to align production rates, workforce levels, inventory levels and other related resources with forecasted demand to align with fluctuating and uncertain demand. Long-term strategic planning involves product development whereas short-term planning involves scheduling practices in the production area. In APP it is crucial to consider uncertainties such as the uncertainty of raw materials supply, limited production capacity and customer preferences. These uncertainties should be considered due to the medium-term capacity planning of APP and the nature of it. In recent studies APP has been incorporated in decision making models to consider changing variables in industrial environments. (Jamalnia et al. 2019, 159-160; Galankashi, Madadi, Helmi, Rahim, & Rafiei 2022, 1959.)

Advantages in aggregate planning include simplifying the planning scope to manage resource allocation and enhancing decision-making. This can be beneficial in medium- to long-term scheduling. However, challenges related to this include balancing the model accuracy and complexity of the project. (Carvalho 2015, 188-190.)

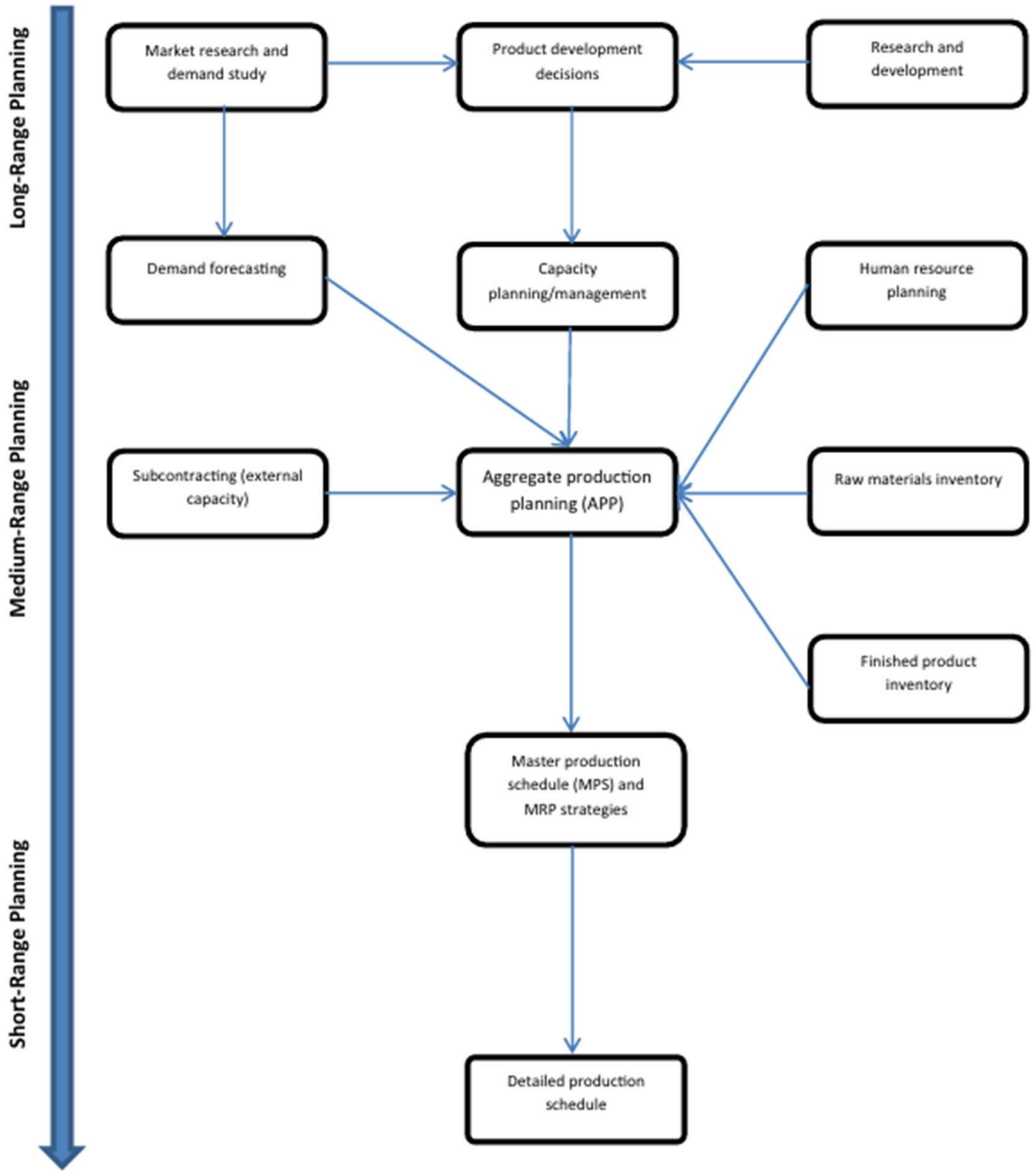

Figure 1. Production planning and control activities (Jamalnia et al. 2019, 160).

Long-range planning builds foundations for a company's production strategy. This phase of planning spans several years and enhances organizational strategy, and market demands with long-term goals. Understanding the current market trend and demand is crucial in production planning. During this phase the understanding of customer preferences and potential market gaps is important. The data gathered during this enables process, product and resource optimization. Research and development have a crucial role in sustaining competitiveness and developing advancements in new manufacturing methods, incorporating and testing new materials as well as integrating new technologies. Demand forecasting falls within the long-

range planning section where future demand enables companies to allocate resources efficiently and estimate fluctuations. (Jamalnia et al. 2019, 159 & 175-176.)

Medium-range planning consists of focusing on aspects within a few months of a project. This includes aligning capacity planning and management with demand. During this phase, ensuring that resource availability is as expected, and possible bottlenecks are minimized. In addition, during this phase ensuring that workforce resources are as needed is crucial. Workforce optimization includes efficient shift scheduling. In addition, this phase involves examining the need for subcontracting. Instances where this could be used are when capacity levels exceed available capacity and schedules are tight. (Jamalnia et al. 2019, 159 & 175-176; Zanella & Vaz 2023, 2.)

Short-range planning includes creating and finalizing the master production schedule (MPS) where the manufacturing schedule is conducted, and production timing is created. The MPS defines which products are manufactured, the timing and the required quantities. Based on the MPS a detailed production schedule (DPS) can be formed which indicates start and end dates of production, required resources and other relevant details needed during the operational phase. (Zanella & Vaz 2023, 2, 11.)

2.3.1 LEAN scheduling approach

The principle of Lean Manufacturing (LM) is to eliminate waste by improving the overall effectiveness and efficiency. This method is often applied to production planning and used in numerous companies in varying industries. (Galankashi et al. 2022, 1959.) LM can be defined as achieving excellent performance by reducing waste by developing a value stream. This impacts to the overall financial performance and enhances efficiency. The waste, which is reduced can be such as excess material, activities which do not contribute to value, excess inventory or in the case of production planning, excess time. Reducing activities which do not contribute to value leads to a more attainable and consistent schedule. (Sakthi Nagaraj and Jeyapaul 2021, 1337; Pinto, Matias, Pimentel, Garrido Azevedo, Govindan & SpringerLink 2018, 9.)

The main objective of lean is to eliminate waste through the whole value stream and have a positive effect on the whole supply chain network (Naeemah and Wong 2021,1080).

Different techniques related to Lean include Single Minute Exchange of Die (SMED), Kanban, Kaizen and Heijunka which can be implemented to streamline production. These methods vary from each other based on their specific focus and applications. These methods can focus on the reduction of flow time, flexibility of production and others such as focusing on reducing disturbances which can be classified as variations. SMED is lean tool used to reduce set up times in production processes. The aim is to schedule workstation capacity efficiently by optimizing workloads and minimising changeover times. (Pinto et al. 2018, 73.) While utilizing lean techniques, it is often suggested that focusing on all lean methods may be beneficial for improved production efficiency. Figure 2 represents a pillar illustration by Tokola et al. 2017 with a foundation build based on the Toyota production system (TPS). (Tokola et al. 2017, 171.)

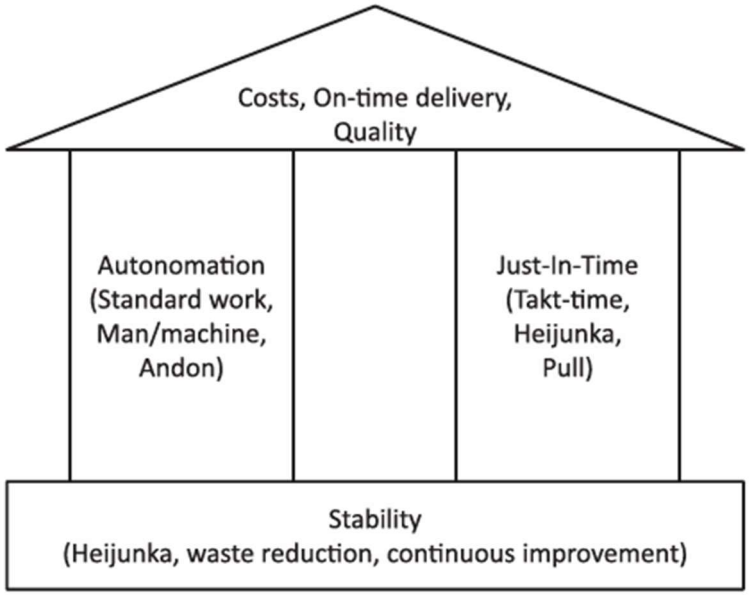

Figure 2. House of Lean (Tokola et al. 2017, 172).

The pillars in the figure above are formed based on lean which is based on the Toyota production system. The two pillars on either side are smart automation and the just-in-time (JIT) method which stand on the foundation. The foundation forms the stability including waste reduction and improvement. (Tokola et al. 2017, 172.) An example of waste can be identified as time (Naeemah and Wong 2023, 1080.) The top parts of the illustration above

include the objectives such as optimal delivery times, costs and quality. These pillars and structures are known as House-of-Lean. (Tokola et al. 2017, 172.)

Tokola et al. 2014 researched three types of operating conditions which form the basis of Lean principles. These three types of operating conditions include: flow times reducing production quantity, local control which can be described as the reduction of lot sizes and third, variation reduction such as increasing flexible capacity. To achieve minimize flow time, work-in-progress (WIP) should be minimized, batch sized reduced, and capacity expanded. It was noted that when the utilization is high, a decrease in WIP affects the flow time by reducing it. This is dependent on the production type and increments. A lean method often used in tandem to reduce WIP is the Kanban method. (Tokola 2014, 2.)

Shahsavar, Sadeghi, Shockley, & Ojha, D (2021) researched a lean scheduling approach in ship manufacturing where the objective was to determine an approach which minimises two types of waste - overproduction and waiting periods. This research was conducted to improve the overall performance and eliminate excess waste. The study was based on the comparison of three approaches: lean scheduling approach, Microsoft project software and mathematical models. The results indicated that implementing a lean scheduling approach reduced the two types of waste which were identified, overproduction and time. It was stated that the lean approach had a better overall effect in the production area minimising non-operational times. The other approaches had longer idle times compared to the lean scheduling approach which affected the overall production time.

Lean scheduling production practices can be described as “pull” systems whereas traditional approaches differing from lean can be described as “push”. The major difference between these two approaches is a customer centric task scheduling practice utilized in the “pull” system. The aim is it minimize inventory costs and operate based by a customer-driven scheduling system. The shift from traditional manufacturing to LM is more than a process change, effecting the whole operational strategies and operations. This change often has substantial effects affecting the whole business process requiring major investments in both time and cost. Before implementing this change, it is essential to understand the scope and impact of said changes. In addition, multidisciplinary expertise is essential to examine the

current state of manufacturing and compare it to desired LM operations. (Ivezic, Potok, & Pouchard 1999, 58.)

2.3.2 Just-In-Time

The main objective of just-in-time (JIT) practice is to move from concept to practice efficiently in a timely manner. This includes utilizing Lean tools such as kaizen, the pull system, 5S, takt-time and SMED. (Pinto et al. 2018, 27.) The 5S tool and kaizen methods are used at an operational level on the manufacturing floor reducing different types of waste (Tokola et al. 2017, 173). Takt-time refers to the rate of production in comparison to customer demand. It is determined as dividing the available working time per day regarding customer rate per day. The pull system, for example, Toyota Production System (TPS) aims to improve efficiency through eliminating waste. This method involves the Kanban system and heijunka which is known as production smoothing. (Pinto et al. 2017, 93, 96.) JIT is based on five core principles:

- creating added value
- systematic leadership
- information flow throughout the process
- responsibility throughout
- ongoing planning and coordination

These highlight the importance of cross-functional collaboration and information flow throughout the process. Creating added value refers to an in-depth analysis of the whole production time and defining lead times considering material availability. Systematic leadership consists of understanding customer requirements and addressing them. It also involves managing situations during sudden challenges and generating profitability. Information flow covers the whole manufacturing period from first steps to the final delivery of the product and possible customer feedback. This consists of information in each phase which should be available when needed and the information flow should be maintained. Responsibility throughout refers to information flow where the team or people in charge of

each phase of manufacturing must take accountability and ensure optimal information flow. In addition, it refers to adding value to the information and providing all necessary information for the next phases. Ongoing planning is done to prevent bottlenecks and address any issues as soon as they arise. (Pinto et al. 2018, 27-29.)

JIT can be implemented for instances where inventory levels are minimal, and the aim is to reduce the capacity of the inventory. In JIT processes inventory costs are minimized by scheduling the material flow regarding the demand. Overall, this method can reduce the total cost by reducing the time materials are stored which can be costly. JIT focuses on on-time delivery for both raw materials and the delivery of the product. This is done by establishing criteria for material management and a schedule where materials are delivered to the manufacturer before production phase is undergoing with a tight schedule to decrease inventory times. JIT focuses on inventory turnover ratio and reducing the lead times effecting the overall expenses in a positive way. (Rivera-Gomez et al. 2024, 281-282.)

JIT can be applied to production planning through scheduling as well as manufacturing. Orders are not always executed as early as possible due to inventory holdings. In production planning, JIT is used to create an efficient manufacturing system while considering quality, cost, personnel and delivery. (Pinto et al. 2018, 29-30.) The focus of JIT is on production floor physical operations and operations scheduling. JIT originates from the Toyota Motor Company by Taiichi Ohno and Shiego Shingo which focuses on the Kanban pull production scheduling and control method. (Ho and Chang 2001, 177.) The Kanban is a pull-based production and inventory control system which controls manufacturing operations based on actual compared to forecasts. It is an information system which aids in managing production in a JIT system by controlling production, needed quantities and lead times. (Pinto et al. 2018, 83.)

Ho and Chang (2001) conducted a study on the integration of JIT production with Material Requirements Planning (MRP) to model schedules which specify the quantity, timing and machines. The adaption of both methods JIT and MRP, combines both scheduling and capacity planning. This study focuses on a discrete production system with multiple machines, managing operations for different assemblies while considering machine capacities, setup times as well as time-varying demands. This type of framework can be beneficial for complex manufacturing systems involving products with multilevel bill of materials (BOM).

2.3.3 Mathematical models in production planning

Often different mathematical models can be utilized to conduct scheduling models based on the needs of said planning. Chinos & Vakhania (2017) carried out a study based on single-machine scheduling model where a job is scheduled based on the release date and due dates. This was based on a model where *n* jobs were released for scheduling at specific integral times. These jobs or tasks were given processing time requirements and a due date determining when that specific job or task had to be completed for it to be on time. Tasks which are completed after the given due date are considered late and did not attain requirements. The aims of this study were to determine an optimal model for minimizing the maximum lateness of the tasks and jobs, defined as the difference between the completion time and given due date.

Graham, Lawler, Lenstra & Rinnooy (1979) introduced a conventional three-field notation for scheduling problems. This theoretic scheduling model consists of three aspects which are job type, machine type and processing time. The job type refers to the specific task or operation which is scheduled to be complete. Machine type refers to the resource needed to complete the job. Processing time indicates the amount of time which is needed to complete the job. These three aspects form the basis of scheduling models including resource allocation and job sequencing.

Chinos & Vakhania (2017) implemented Grahm et al. (1979) conventional three field notation theory to determining a model for scheduling based on release date and due dates. In this instance, the machine environment (a single processor), job parameters such as processing time as well as release time of the task and the criteria which in this instance is maximum lateness of the task. In this study this was abbreviated to:

$$1|r_j|L_{max} \tag{1}$$

where "1" stands for the single processor, r_j is the release time (r) for a specific task (j). The lateness of said task which is being schedules is implied as L_{max} standing for the maximum amount of lateness. (Chinos & Vakhania 2017, 3.)

2.4 Forecasting and demand planning

Forecasting and demand planning is a crucial part of ensuring that production capacity aligns with market demand. Constant fluctuations in market demand makes it important to utilize forecasting tools to predict production related needs as accurately as possible. The challenge often lies in customer orders, which can lead to capacity constraints. Finished goods which are ready to be delivered to a customer with a short lead time are directly correlated with the customer service level of a company. Forecasting demand can be described as predictions based on data and is often subject to changes with the nature of customer orders. The stock level must be at an appropriate level considering that additional stock creates unnecessary costs which is reflected towards the customer in the prices of finished goods. In addition to this, stock level must be at an optimal level to satisfy customer needs and shorten leads times. Maintaining high inventory levels ensures a high level of customer service. However, it is as important to reduce stock to lower working capital and enhance the overall efficiency of a company. (Makajić-Nikolić, Babarogić, Lečić-Cvetković & Atanasov 2014, 711-712.)

2.5 Master production schedule

A master production schedule (MPS) is a plan which ensures efficient production planning. Frequent changes to the MPS can cause disruptions in planning and production. The MPS lays the framework for production where plans are formed into schedules for raw materials, labor and workstations. (Amaranti, Muhammad, & Septandri 2020, 1.) Planning processes start with a master production schedule where the output forms planned orders for internal production and procurement requisitions for externally sourced items (Jodlbauer & Strasser 2019, 2).

The MPS is a tool used to maintain customer service levels and ensures stable production planning in a MRP environment. The main objectives of MPS include forming end-product schedules based on aggregate planning, evaluating different schedules effectively, evaluating raw material requirements, assessing production capacity and ensuring effective use of production capacity. (Amaranti et al. 2020, 1.)

2.6 Material requirements planning

Material Requirements Planning (MRP) is often used in manufacturing processes involving complex multi-item production and is used as a tool in manufacturing management. MRP is based on basis that materials required for manufacturing can be forecasted based on the structure of the product which is manufactured. The demand is based on the structure of the product which is outlined in the Bill of Materials (BOM). MRP ensures that right materials are available at the right time in the correct quantity. MRP works based on key input such as the MPS, BOM and inventory records. By processing these inputs, MRP system generates planned order releases which helps with inventory levels and enhancing production efficiency. (Ho & Chang 2001, 176.)

One primary challenge of MRP is determining the lead time which has multiple factors to consider such as processing time, material availability and set up time. Lead times in production are critical because it affects the overall scheduling of orders and are determined how much time takes to obtain the required capacity for each order. These phases which make up the lead time can vary based on different variables such as set up time. (Ho & Chang 2001, 176). While MRP offers several lot-sizing methods which often rely on suboptimal methods due to capacity constraints. One disadvantage regarding MRP is the inability to form detailed schedules which consider the capacity of the production stations, work centres or machines. MRP does not reflect real-world capacity constraints. (Ho & Chang 2001, 176; Jodbauer & Strasser 2019, 1.) Purchase orders can be generated by applying MRP. Planned orders' items subcomponents determine the need for purchased materials or items. (Jodlbauer & Strasser 2019, 8.)

2.7 Capacity planning

Capacity planning refers to meeting demand with resource availability and the efficient use of resources to ensure optimal production output (Carvalho et al. 2015, 188). Production capacity can be controlled by determining and controlling the number of shifts, personnel, overtime shifts, number of machines and workstations (Ghadimi & Aouam 2021, 533). Capacity planning ensures production aligns with work centre capacity and shifts meet demand, producing the needed quantity on time (Sarferaz, 2022, 156). This is a key factor

in any production planning processes. Capacity planning is done to evaluate the volume of capacity and ensure that enough resources are available to meet demand. It involves analysing current capacity, forecasting future requirements. It is done to avoid overcapacity or underutilisation. This is called capacity evaluation. It enables companies to identify bottlenecks by determining ideal situations for work centres. (Goel 2022, 201.)

In capacity planning both on-demand and consumption-based item should be considered. Consumption-based items refer to items which have a reorder point and where lot-sizes are determined. These items are restocked based on consumption rather than specific production orders such as on-demand items and are ordered when inventory drops lower than determined. Production capacity must be assessed throughout to ensure it is sufficient for required resources. Capacity planning is based on drafted order receipts which then are scheduled to meet the required completion date of a production order. Only internally produced items are accounted for in capacity planning. Necessary adjustments must be made if capacity constraints arise. To achieve a balanced capacity load three key steps should be followed:

- evaluating cumulative capacity
- resolving capacity constraints
- reducing available capacity to meet demand.

Various methods can be used to minimize and mitigate constraints. These include utilizing alternative resources when available, implementing lot summarizations, adjusting capacity with increasing work hours, additional personnel or shift modifications. The method which is most often used first is rerouting production orders to alternative resources. Lot summarization is used when smaller orders are merged into a single larger order. This method reduces setup times but may lead to increased inventory levels and inventory costings. The last resource often used is additional capacity with overtime or additional personnel. If these methods are insufficient the postponing of requirements or accepting delays may be necessary. (Jodlbauer & Strasser 2019, 5-8.) Advancements in ERP systems provide efficient solutions for capacity check improving the overall planning accuracy (Tenhiälä 2011, 66.)

2.8 Key Performance Indicators (KPIs) in production planning

Key Performance Indicators (KPIs) are used to measure and manage business performance within a company. Measuring business performance through obtained data from a production process gives insight to an overview of up-to-date information of the overall efficiency of the production process. The data observed through KPIs gives a basis for production planning and assessing the efficiency of resources and equipment. Main objectives of production management include customer satisfaction and efficient utilization of available production resources. Indicators which relate to the efficiency of production include measuring productivity, evaluating equipment effectiveness, production capacity and available timeframes for production. The accuracy of these measurements affects the validity of performance metrics which can be measured by KPIs. KPIs can be such as measuring productivity, product quality and the mean of production costs. Performance in production is evaluated based on production cycles and monitoring production capacity and the utilization of the capacity to its potential. (Rylková, Čemerková, & Pokorná 2021, 2-4.)

Makajić-Nikolić, D. et al. (2014) researched multi-product production planning problem though a multi-period timeframe with limited production planning for make-to-stock production. The objective of this research was to develop an algorithm for the support of dynamic production triggering decisions in relation to two supply chain KPIs, which were the stock cover of a company and the overall customer service level. Various basic assumptions were made regarding the placement of orders from customers which were assumed to be placed through almost all cycles, the demand for each product differs, demand is fulfilled from stock either partially or fully.

Additional assumptions were regarding inventory levels where inventory capacity is not limited, and production assumptions related to the capacity of production which was limited. The algorithm supported a two-phased decision-making process. The developed algorithm can be utilized at both operational and strategic levels. The main function of the algorithm generates a list of products which should be produced, applying one of four predetermined criteria: minimal customer service level and stock cover, high-capacity utilization and high volume of products, while considering the available capacity. Through this algorithm two main realizations were formed, which products can, and which should be produced. (Makajić-Nikolić, D. et al. 2014, 711, 717, 719.)

3 Planning in Enterprise Resource Planning systems

This chapter covers the basics of production planning in Enterprise Resource Planning (ERP) systems focusing on SAP S/4HANA. The principles of ERP and the functions integrated within are examined. The literature covered in this chapter is combined with the literature from chapter 2 is used in the pilot project chapter 4.

3.1 ERP systems

ERP refers to the integrated software systems which supports various business functions within an organization supporting cross-functional operational efficiency. The concentration of this chapter is mainly on SAP ERP solutions which is utilized in chapter 4. However, in addition to SAP other ERP solution providers are available but this study has a focus on SAP. ERP system is a multi-module software which can be used to manage various organizational variables including gathering and storing data, inventory control, procurement, warehouse management and human resources management. ERP systems are often utilized in manufacturing businesses due to the vast variety of operations which can be interlinked trough one system. This is integral in improving efficiency and streamlining operations. The adaptation of said system requires extensive reengineering within a company and retraining which can be time consuming. (Sarferaz 2022, 6-7.)

3.2 SAP S/4HANA

SAP is an Enterprise Resource Planning software (ERP) used in a vast variety of industries and sectors such as manufacturing, procurement, supply chain management, quality, logistics and as well as other sectors including finance. SAP is used to store and access real-time data across multilevel organizations. With access to real-time data companies have the possibility of enhancing the overall efficiency by accelerating workflows raising productivity which leads to an increase in profits. (SAP, 2023a.)

SAP S/4HANA is an enterprise management tool provided by SAP which is the latest version released in 2016 (SAP 2023a; Sarferaz 2022, 7). This version is a more simplified

version of ERP systems offering more advanced features including embedded analytics, simulation, prediction, support for decision making, machine learning as well as artificial intelligence (AI). Functions provided in SAP S/4HANA seen in Figure 3 include specific tools used in production planning, materials management, finance and controlling, plant maintenance, human resources, sales and distribution and more. (Goel 2022, 5.)

Figure 3. Business functions in SAP S/4HANA (Goel 2022, 5).

As digital transformation grows across industries, the importance of advanced ERP solutions continues to advance. This is driven by the increasing need to attain fast, reliable deliveries and secure transactions across different platforms. The connection between production planning with manufacturing operations have been linked through systems such as the master production schedule (MPS). These enhance operational efficiency and aid in aligning production capabilities with financial planning. (Sarferaz 2022, 3-4.)

3.3 SAP production planning

SAP Production Planning (PP) is a module in SAP S/4HANA which is used to manage production processes within organizations. The PP module on SAP offers users access resources such as demand planning, master production scheduling, MRP, capacity planning and scheduling. SAP PP is a key module in SAP which tracks and records the production process, including monitoring both planned and actual costs. (Goel 2022, 6, 15, 345.) In addition, SAP PP tracks goods movements such as the transformation of raw materials into semi-finished goods. Additional benefits of SAP PP include the integration of this module with other SAP modules such as SAP Sales and Distribution (SD), Materials Management (MM), Quality Management (QM), Financial Accounting and Controlling (FICO) as well as Plant Maintenance (PM). (Carter, 2019.)

The PP module within SAP provides organizations tools to effectively plan the production phases seen in Figure 4. Using these tools or the combination of them companies have the possibility to achieve operational efficiency based on the specific production planning requirements. (Goel 2022, 5-6.)

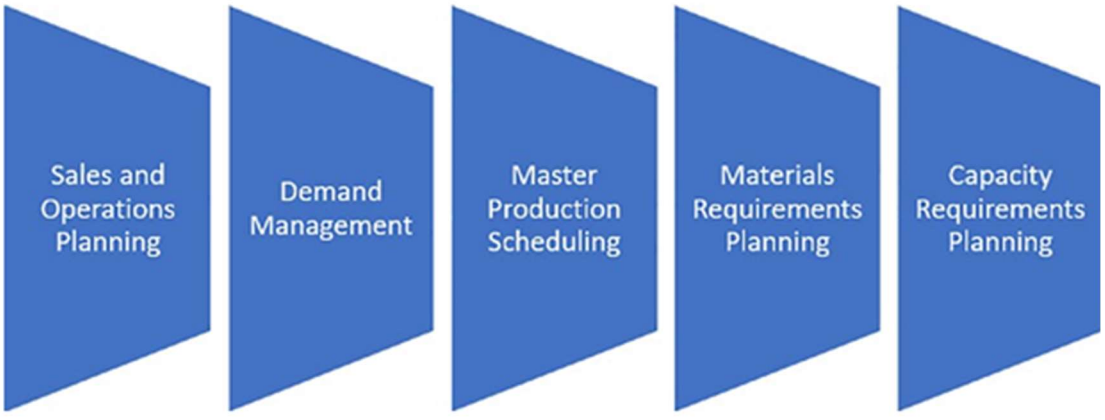

Figure 4. Production planning tools in SAP PP module (Goel 2022, 6).

Sales and operations planning (S&OP) is used as a forecasting and planning activity in SAP which aligns sales forecasts with production capacity and inventory levels to balance

demand and supply based on historical current and forecasted data. S&OP is mainly used for long- and medium-term planning to aid inventory, lead-time, pending work, capacity and demand planning. (Goel 2022, 90-91; Sarfraz 2022, 141.)

Demand management is a link between S&OP and material requirements planning (MRP) where inputs are received from S&OP and transferred to MRP. Demand management is considered a submodule in SAP where the quantities and scheduled delivery dates for completed products are calculated. It utilized two key components: planned independent requirement (PIR) and customer requirements which are calculated during an MRP run. A PIR represents a demand for material used in planning which can be created manually or transferred from S&OP. Customer requirements are demands received from sales orders or scheduling agreements. Demand management is a crucial aspect in make-to-stock production where materials are produced based on historical data and future forecasts. (Goel 2022, 38, 109-110, 115.)

Master production scheduling (MPS) is a planning process comparable to MRP but is used to ensure that high-demand and critical finished goods are available for production and delivery. The main difference between MPS and MRP is that MPS focuses on products whereas MRP focuses on materials. MPS can run separately or before MRP. (Goel 2022, 30, 144.) MRP ensures that supply elements meet demand but does not consider available capacity. Purchase requisitions and planned orders are the product of an MRP run. (Sarfraz 2022, 127, 139, 156.)

SAP provides consumption-based planning tools such as reorder-point planning, forecast-based planning and time-phased planning which are a type of MRP. Reorder-point method is used in situations where stock levels must be maintained efficiently by automatically creating procurement proposals. Inventory levels for reorder point planning are set in advance in MRP 1 View SAP master data. Procurement proposals are created when a planning run is executed. Forecast-based planning requirements are based on historical data. Time-phased planning is used when materials should be delivered in intervals. This can be used in situations where vendors deliver materials on specific days (Goel 2022, 30, 145.)

Capacity requirements planning relies on accurate master data, especially work center and resource allocation. Work centers support key functions such as scheduling, cost analysis

and capacity management. Routings or material receipts define the sequence of tasks needed to manufacture specific products.

Production planning in SAP PP focuses on combining all elements mentioned above by considering material availability and production capacity. The main steps include planning raw materials based on the BOM for finished products and generating procurement requests based on this. Capacity planning involves aligning production requirements with available capacity at work centers. MRP is used to ensure material availability and address shortages by monitoring supply and demand. While MRP is used to access material needs, capacity planning must be executed to ensure that production schedules align with work center capacity. If capacity constraints arise, they can be managed through adjusting work time or shifting schedules. (Saferaz 2022, 154-156.)

3.3.1 Master data

Master data is created location specifically at a plant level indicating which parameters are set for a specific plant. The data behind items can differ between plant locations within an organization and are set based on individual activities. Master data for items and materials in SAP are mainly static and seldom changed. The master data used in the PP module includes (Carter, 2019):

- Routing
- Work Center
- Material Master
- Product Version
- Bill of materials.

A material master is created for each item used within a plant. It contains all information related to the material used including manufacturing, procurement and inventory management. The material master contains multiple different views for different business transactions, enduring that all relevant data is captured. (Goel 2022, 16.) The bill of materials (BOM) is a list of materials required during the manufacturing process indicating the quantities (Sarferaz 2022, 110). Whereas the work center indicates an activity or operation which is performed to manufacture said product. Different types of work centers include

machines or labor. These work centers which are created for manufactured products are used in routings. A routing is a task list which contains all production steps such as operations, work centers and durations. A production version is created for each product which is manufactured. Production versions are done to form a relationship between BOM and routing. (Goel 2022, 16-17.)

3.3.2 Production order-based manufacturing

In production order-based manufacturing also referred as discrete manufacturing in SAP is done through planned orders which are executed and scheduled into production orders. This method is often used when materials are produced in batches or lots and the manufacturing materials change frequently. Discrete manufacturing can be implemented when small quantities with high complexity or larger quantities with lesser complexity. This method often involves detailed multi-level BOMs and product configurations which change frequently from orders to another. (Goel 2022, p. 8, 10, 227.)

Production Orders are documents which inform what needs to be produced, when it should be executed and in what quantity. Planned orders form the need for executing and scheduling production orders. Before production orders are carried out in production they are released in SAP. During these the final material availability checks are conducted and lets the user know if there are any missing components. (Carter, 2019.) Production orders are formed from planned orders which are outputs from a MRP run within SAP. MRP can be manually run using the interface MD01N *MRP Live* or automatically. (Sarferaz, 2022 156.)

There are multiple ways of creating a production order from a planned order such as using transactions MD04 *Monitor Stock / Requirements List* which displays the stock requirements list for specific materials, C040 *Converting Planned order to Production order* tile or CO41 *Convert Planned Orders to Production Orders*. In MD04 production orders are created selecting the planned order which is displayed as “PldOrd” and then selecting the icon “Prod. Ord.” which is used to convert the planned order to a production order. Before executing the planned order to a production order, the quantity of said product should be checked to see if it matches expectations and scheduling the start date of the production order should be set. These details can be seen in the production order details which additionally include the

material information, MRP type, MRP controller, plant, production dates and quantities. (Goel 2022, 229- 233.)

3.3.3 Production planning and detailed scheduling

Production planning and detailed scheduling (PP/DS) can be used in SAP S/4HANA as tool to increase and maximise production efficiency in addition to reducing costs of production by optimizing the planning phase (Goel 2022, 348; SAP 2023b.) Master data needed for PP/DS in S/4HANA includes locations such as a specific plant, material master where PP/DS can be activated in MM02/MM03 view "Advanced Planning". Advanced Planning view is shown in Figure 5.

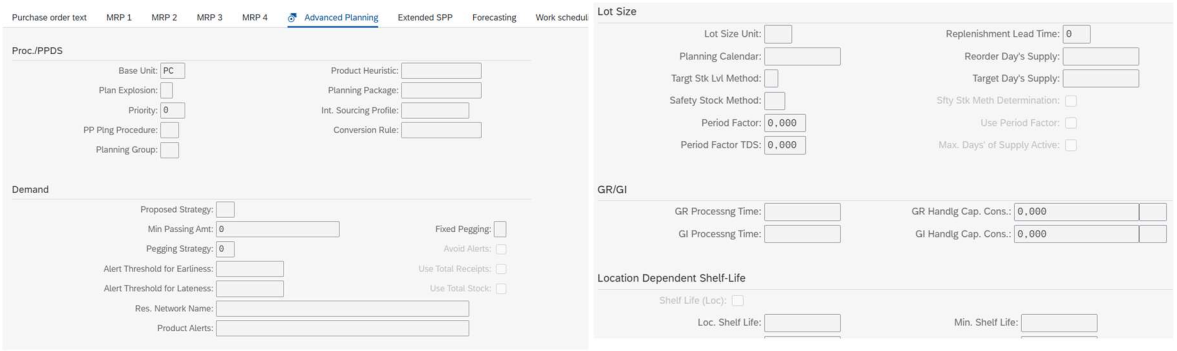

Figure 5. MM01 – Advanced Planning view in SAP

Material data such as product heuristics which are the planning function, priority, planning package, PP Planning procedure, interactive sourcing profile, planning group, proposed strategy, lot size unit and goods receipt (GR) processing time can be determined as well as other needed data which can be seen in the figure above. The proposed strategy section is used to for demand planning and is similar to the strategy group defined in MRP3 view. During this, strategies such as make-to-stock (MTS), planning with final assembly or other functions can be used. (Goel 2022, 346-354.)

SAP S/4HANA and PP/DS maintain different planning data as seen in Figure 6. These are tightly integrated, where each system handles specific aspects of production planning. S/4HANA manages material data and production versions which are linked to PP/DS. The

data in PP/DS focuses on detailed scheduling (DS), sequencing of orders and operations as well as capacity planning. Planned dates however cannot be overwritten in S/4HANA and scheduling decisions made in PP/DS must remain, while these are synchronized to S/4HANA. (SAP 2023b.)

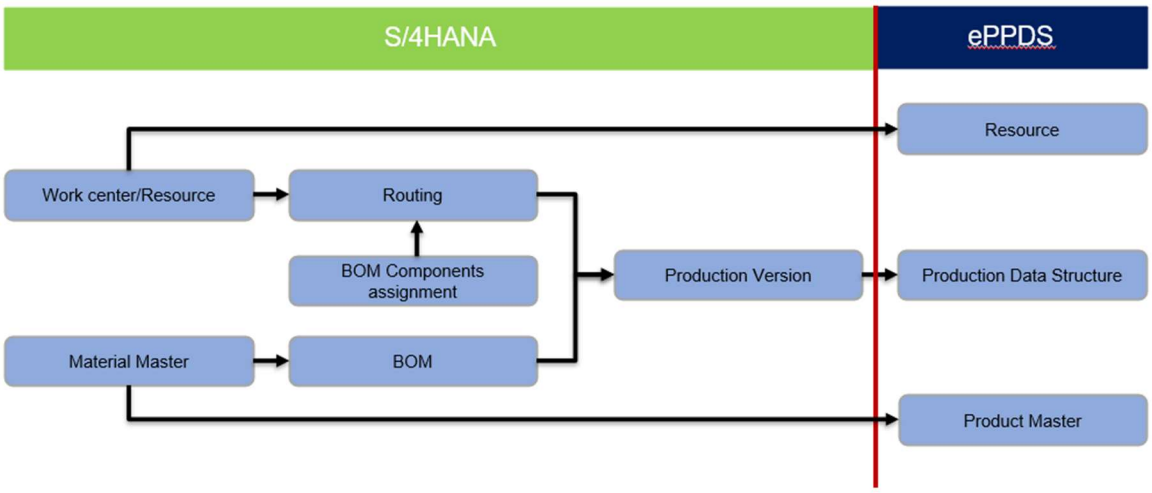

Figure 6. Integration model of SAP S/4HANA and ePPDS – Master data overview

The routing data in S/4HANA is created it is used to create the production data structure (PDS) which determined the intervals for each component. Sales and project orders are created in S/4HANA and the planning for them are executed in PP/DS. This process involves using heuristics to plan and optimize sequencing of task to ensure that they are completed as needed.

Additional tools which can be used to check if there are any inconsistencies between S/4HANA and PP/DS include comparison of the change date. This function compares the master data in S/4HANA with PP/DS production data structure (PDS) and provides an overview of weather updates have been transferred between these. An explosion result comparison can be used to compare production and process orders in both systems. (SAP 2023b.)

PP/DS extends production planning and scheduling functions to a visual format called detailed scheduling board (Figure 7). Detailed scheduling (DS) is tool used for sequencing operations and visualising available capacity per workstation. During this capacity constraints and component availability are considered. During this forward or backward

scheduling can be used and resulting is done by moving specific operations to different time slots. The DS considers errors such as missing components or capacity overload and does not allow orders to be moved to timeslot which produce these errors. (Goel 2022, 372-380.)

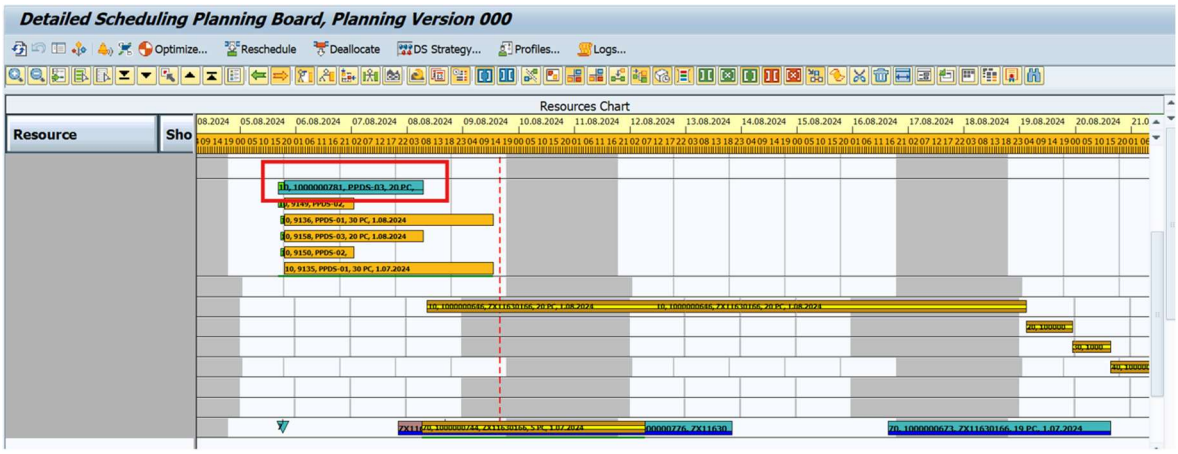

Figure 7. Detailed Scheduling Planning Board display in SAP

PP/DS is used to manage the planning and scheduling of a production process. A representation of PP/DS in a matrix is shown in Figure 8. In PP/DS ongoing orders and minimum stock levels are derived from demand planning. PP/DS is used to determine the resources needed and initiating the production. (Schultmann, Fröhling, & Rentz 2006, 1593-1594.)

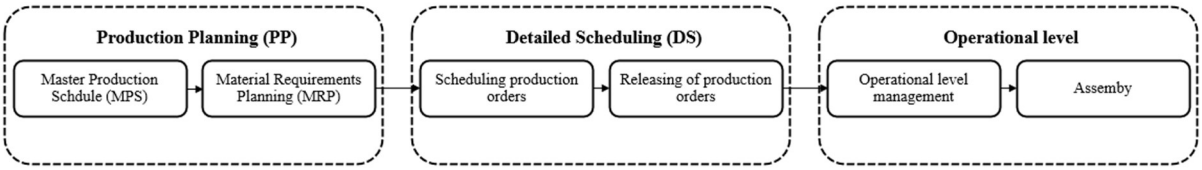

Figure 8. Production planning and detailed scheduling matrix (adapted from Schultmann et al. 2006).

The PP/DS system transforms order-related and forecast driven requirements into production plans. This process starts with evaluating current customer orders and anticipated demands considering capacity and resource allocations. A function within PP/DS involves sequencing

tasks based on operations, availability and priorities. These schedules must be monitored and rescheduled if needed. (Schultmann et al. 2006, 1593-1594.)

In PP/DS planned orders can be converted to production orders. One advantage in PP/DS while converting orders is that errors are generated during this if any issues arise. Alert profiles can be created for different applications where the system will automatically generate an alert if a problem is identified such as capacity constraints or material availability. (Goel 2022, 372-380.)

4 Research methods

This chapter covers the practical phase of this study where production planning of a PF modernization is analysed. This pilot project is conducted for a company in the filtration industry focusing on a specific manufacturing plant. The focus is on unifying production planning to a production order-based manufacturing where projects are linked to production orders in SAP S/4HANA. This method is currently implemented on smaller tasks such as spare part assemblies and own component manufacturing at said company. This pilot project consists of larger scale assemblies with more complex structures and time-consuming assemblies compared to smaller assemblies such as spare parts. Table 1 represents the overview of different production types and the tools used in SAP at the plant in question.

Table 1. Overview of different project types and SAP tools in said company including the pilot project

Process	Tools used in SAP	Description
Customer Projects	PS Project Builder	Used on previous and ongoing projects as a planning platform
Pilot Project	PS Project Builder PP module Planned Orders	Combination of structured project tools and pre-scheduled order planning
Spare parts	Sales Order Planned Orders	Planned orders based on sales orders
Stock refilling	Reorder point planning Planned Orders	Automated planning through material master re-order point which is activated when minimum levels are reached

As seen in the table above customer projects are planned through the PS system where subcomponents are entered to Project Builder in SAP. Compared to the new method under investigation in this pilot project, the top-level assemblies are entered to Project Builder which forms a planned order after an MRP run. These planned orders are then opened as production orders following the schedule created in Project Builder.

4.1 Project scope

The scope of this project involves collaboration between engineering, production planning, procurement and component fabrication in manufacturing. The key aspect of the project's planning phase is the coordination between the production phases to minimize bottle necks and ensure seamless transitions. The primary focus of this pilot project is on production planning, other key considerations include, workforce allocation, supply chain management and optimized workflow at an operational level. Material availability and coordination between teams play a critical role in meeting project targets. In addition, the project scope includes risk assessment of factors which can impact the manufacturing stage. These risks can be such as supply chain disruptions, equipment or machine failures, poor planning regarding schedules and workforce constraints.

The project in question is a modernisation for a PF filter including multiple mechanical assemblies and an electrification. The mechanical assemblies involve the integration of multiple subsystems. These assemblies vary in sizes and structures. The assemblies require precision in manufacturing and alignment to ensure functional reliability. Each component must be assembled in a controlled sequence to meet design specifications. The pilot project consists of multiple assemblies which are presented in Figure 9. These assemblies are executed as production orders in SAP by assigning them to the project structure within Project Builder in SAP. These assemblies include in-house own component manufacturing.

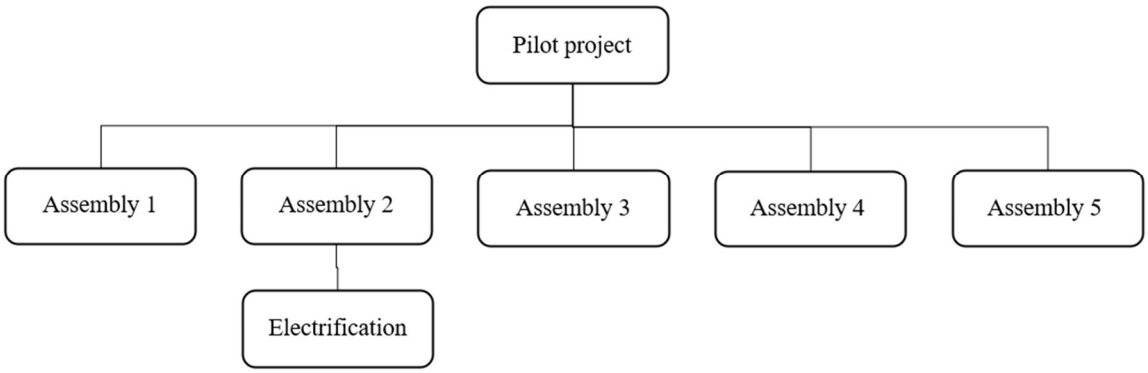

Figure 9. Structure of pilot project assemblies

The assemblies in this pilot project include various subassemblies and phantom subassemblies which are further elaborated in the following sections. The electrification involves installing and connecting electrical systems to ensure that the final product meets operation and safety requirements. This part of the project involves coordination between the mechanical and electrical teams to align the assembly procedures with wiring and control system installations. Planned orders for these are formed after an MRP run when the main assemblies 1-5 are placed in Project Builder.

The production planning structure of this project is presented in Figure 10. This figure illustrates the relationships between different phases of planning and how they are interlinked.

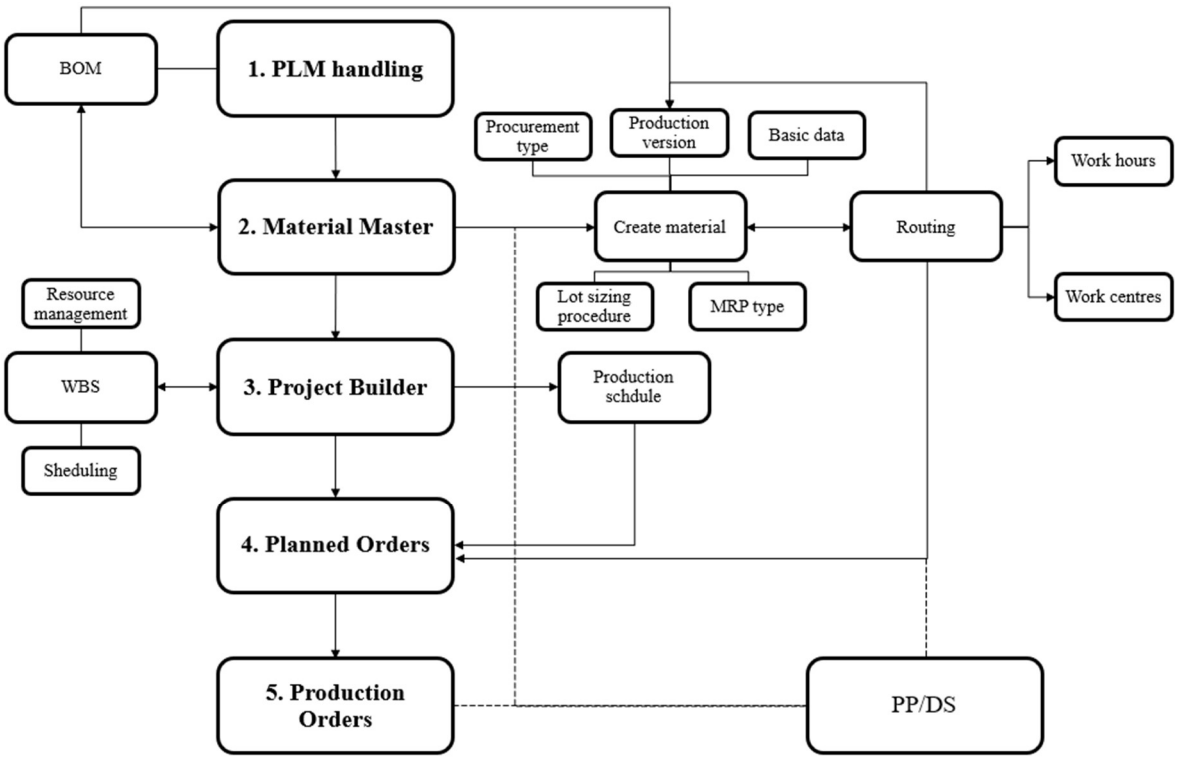

Figure 10. Structure of production planning for the pilot project

The first step after receiving the structure is the structure handling in the PLM system presented in the figure as “1. PLM handling”. During this, different item relationships are connected, the subassemblies connected, and component specifications are made regarding if components are manufactured in-house or procured externally. The data behind the

components are then sent to SAP for material extensions, which is step two in the chart above. Section “2. Material master” is created for each component including subcomponents and assemblies. When the material extensions and routings are done the next step is to place the top assembly item code in Project Builder, section “3. Project Builder”. After an MRP run, planned orders are formed for the top assemblies and in-house own component manufacturing (“4. Planned Orders”). These are then opened as production orders (“5. Production Orders”) triggering procurement requests for subcomponents which have been determined as procured externally.

The planning phase of this project is a critical part in ensuring that operations align with the overall project objectives. In SAP, the planning includes structuring project tasks, managing timelines, and creating planned orders which are formed to production orders. These planned orders indicate the production steps and include routings which are connected to the correct work centres. This allows for a seamless integration of production planning and operational execution. By linking routings to work centres, SAP can effectively allocate tasks based on real-time capacity and resource availability. Planned orders represent production orders which are yet to be scheduled and serve as an indication on upcoming manufacturing activities.

SAP interfaces are used to access and integrate data from various systems, ensuring seamless communication across different departments. These consist of information such as inventory levels and production schedules. The interfaces used in this project are listed in Appendix 1. Some of these interfaces are used as tools for monitoring and others are used to maintain data.

4.2 Material management and routings

After receiving the structure for the project, material masters are created for each component. Material management (MM) in SAP is fundamental in manufacturing and production planning. Materials are created in SAP to ensure seamless integration between modules. Materials are created by extending it to a predetermined plant using MM01. Material extension is when the BOM is sent to SAP from a PLM software and the material data is created. Material masters are used in various modules in SAP such as the PP module.

Standard SAP modules such as MM and transaction codes related were used during this study. The main tools used in the creatin of the material master include the PLM software and SAP transaction codes:

- MM01 – Create Material
- MM02 – Change Material
- MM03 – Display Material

Figure 11 represent the MM01 view where a material code is blocked due to the nature of this project. MM01 transaction is executed by placing it in the command field in SAP. The material number is code which is used to identify specific materials. Each material has its own unique identifying code. These codes are predetermined in the PLM system and are brough to SAP during the initial phases of structure handling. Additionally, the industry sector and material type are defined. The industry sector and material type chosen to determine which data fields are visible in the material master. This information can be set manually but in this instance this data is brought from the PLM system automatically.

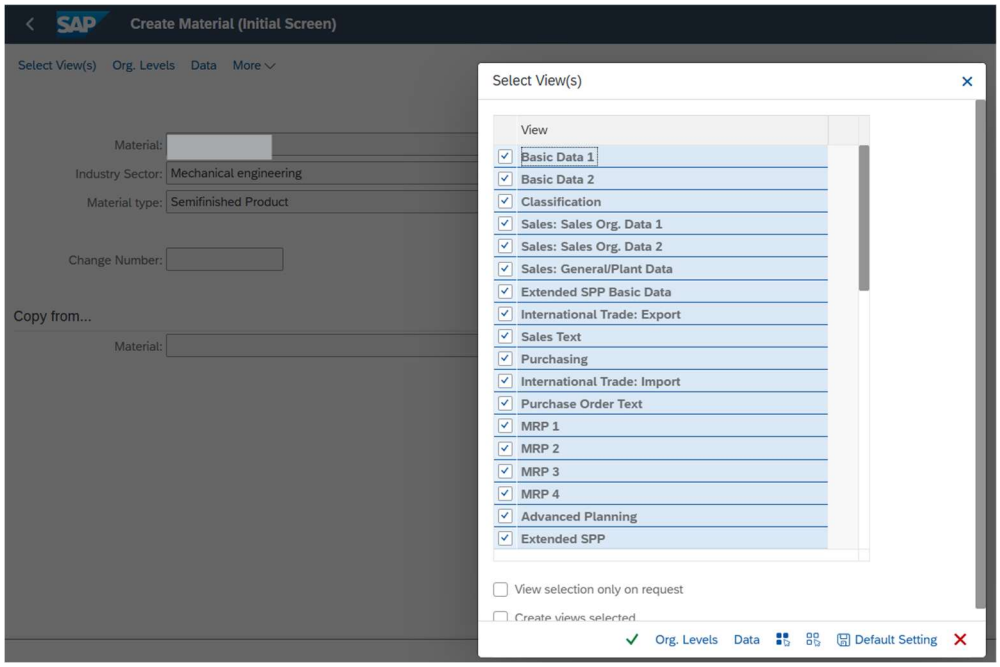

Figure 11. Create Material (MM01) SAP initial view

This project contains multiple structures which include various subcomponents. All items, including subcomponents, are extended to the plant and a material master is created for each component as seen in Figure 11. During this, specific “views” are selected and extended to the plant. If a material master for an item has already been extended to the plant, it does not need to be extended again. In cases where not all necessary views are selected initially, they can be added later by extending the missing views as needed.

Main data entered during this process includes, defining the plant for which items are extended to, tax data, item category group in Sales: sales org 1 and 2 views, availability check, loading group and profit center in Sales General/Plant view, purchasing group, MRP 1-4 views, forecasting view, work scheduling view, accounting 1-2 and costing 1-2 views. During the extension on view “MRP 2” the procurement type for each component was determined shown in Table 2. Once all required values are entered, the master data is saved.

Table 2. Different procurement types in SAP MRP2 view used in the pilot project

Product	Procurement type	Description
Assembly	E	Forms a planned order
Own manufacturing	E	Forms a planned order
Purchased components (such as cables)	F	Forms a procurement request
Subassemblies or items such as cables cut to correct measurements	E50	Done in-house but no planned order is formed or needed

Components which were procured are set as “F” *external procurement* and in-house production such as assemblies or own manufacturing is set as “E” *in-house production* or “E 50” *phantom in-house production*. Procurement type “X” *both procurement types* is not used during this project. This procurement type creates both a procurement request and a planned order after a MRP run. Additional modifications are made using MM02. MM03 is used to display master data.

Once the material master is formed, routings are developed for items that are produced and assemblies. The routing outlines the production process for each item, specifying operations,

the sequencing of operations, and resources needed for each operation such as work centers and durations. The routings for this pilot project include the following elements:

- Operation description
- Work Center
- Duration
- Materials

It is essential that routing accurately reflects the actual manufacturing process to ensure efficient production and prevent bottlenecks. Routings are created using transaction CA01 as seen in Figure 12. This project consists of two different methods of creating routings. Note that routings are only created for assemblies and in-house own component manufacturing.

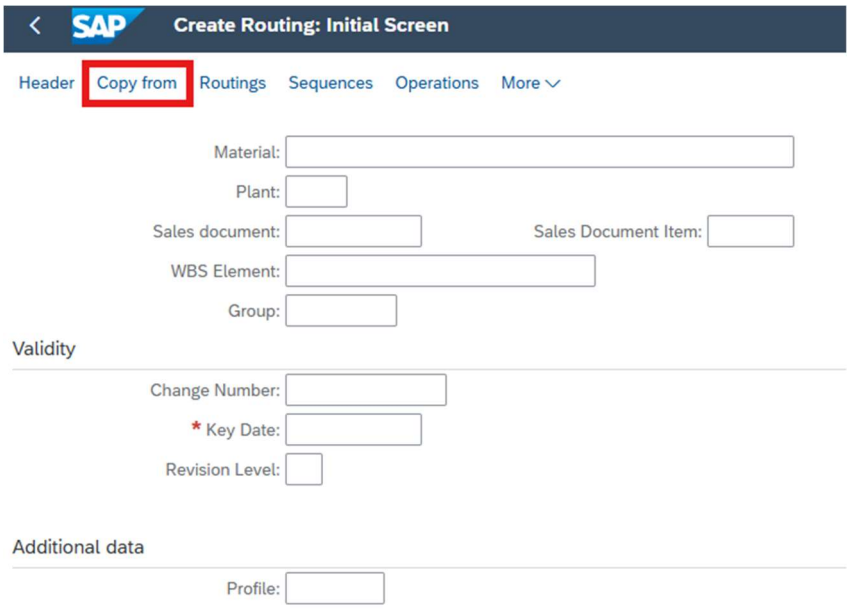

Figure 12. Create Routing: Initial Screen – copy routing from an existing material or create routing from beginning to end

First method of creating a routing involves using “Copy from” function, as shown in the figure above. This approach creates a new routing based on existing reference material.

Work centers and operation durations are automatically created for the new material based on reference. This is used when, for example, a similar item is produced and the template of another item corresponding to one being created matches in work hours and work center allocation. This is done for own-component manufacturing items during this project.

The second method involves creating the routing from the beginning by manually defining each step. This approach is used for the main assemblies, as no previous routings for similar assemblies have been done at this specific plant. This process is carried out using transaction CA01, which opens the same initial view as in the figure above. The material code, plant and key date (the date the routing is created) are entered, and then "Continue" is selected to open the detailed routing view, as illustrated Figure 13.

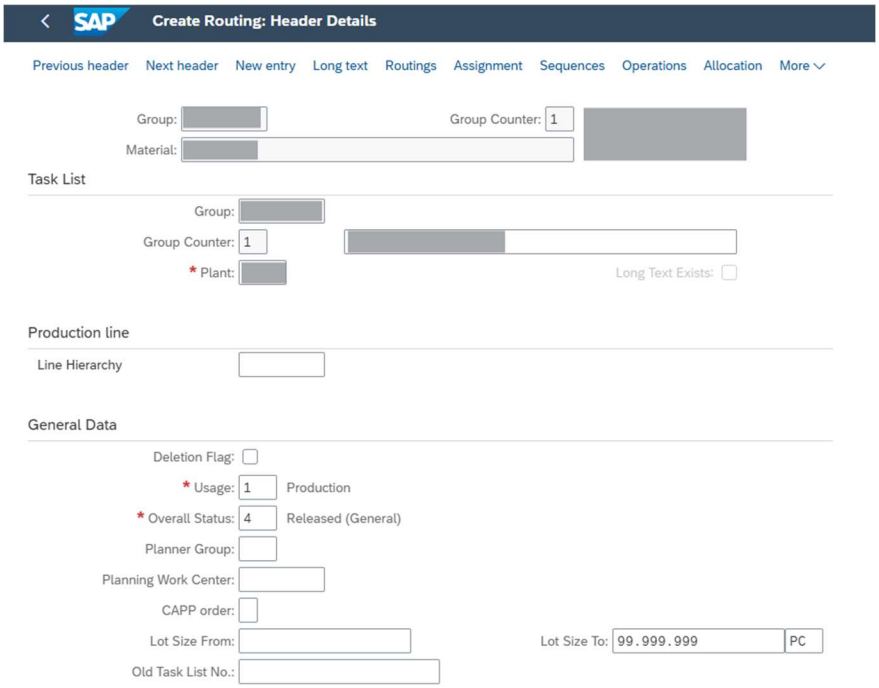

Figure 13. Creating Routing: Header Details - Creating Routings

When a new routing is created manually, as shown in Figure 14, the group counter is set as "1". When the routing is created using "copy from" function, the group counter is "2" or higher depending on how many other items have been assigned to the same group. The group counter indicates the number of items that belong to the routing group. The routing usage is set as "1" *Production* and the overall status as "4" *Released (General).*

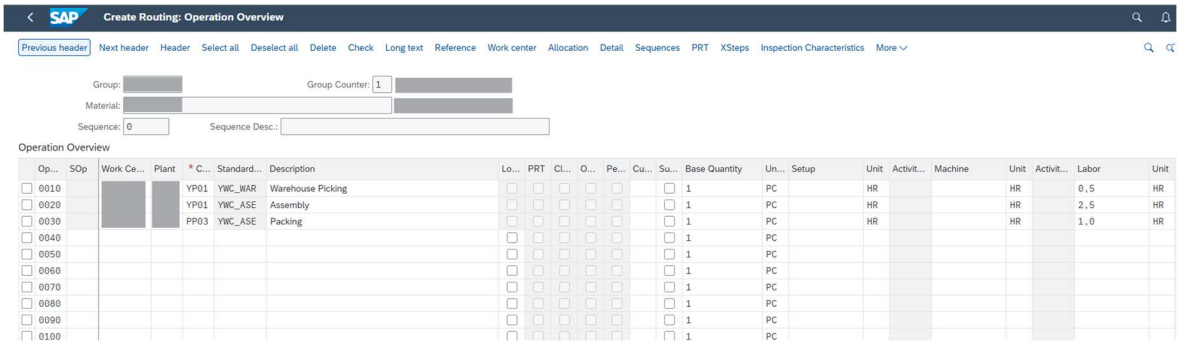

Figure 14. Create Routing: Operations Overview in SAP

This process is applied for all assemblies. Since the assemblies differ, the routings also vary accordingly. The work centers, operations sequence and work hours are all specific to each assembly. For instance, mechanical assemblies require different work centers compared to in-house own component manufacturing. However, the first operation in each routing in this project is the same: the picking operation. When the routing is done it needs to be connected to the material master. This is done for each material which a routing is created for. This is done by accessing MM02 MRP 4 view as seen in Figure 15. Due to the nature of this project the specific routings are not displayed, and operation sequences and durations are not shown.

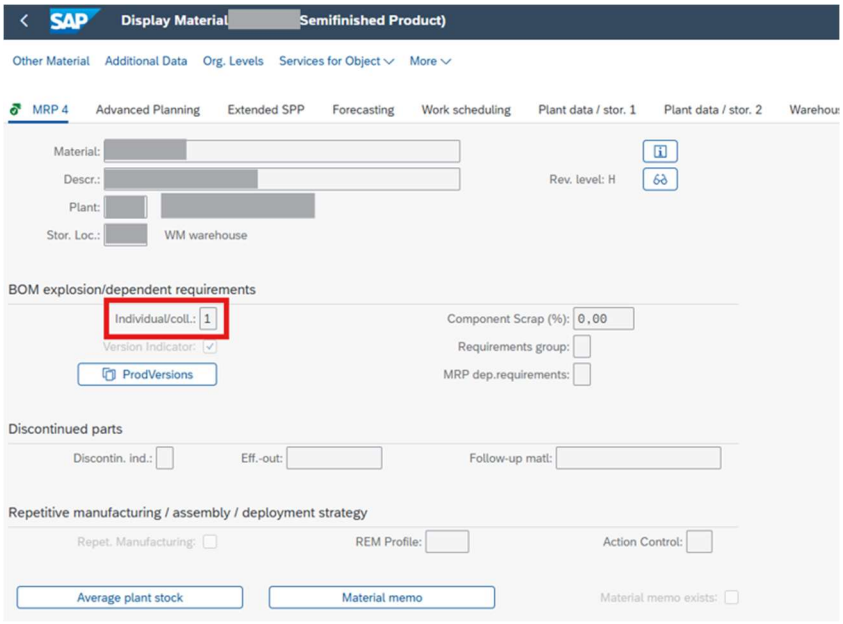

Figure 15. Change material (MM02) – MRP 4 view: creating a production version

As seen in the figure above, section “Individual/coll.” is circled. This is determined during the creation of the material master. Input “1” indicates that this item is processed through project stock. This means that any items with “1” which are connected to a project are bought for that specific project. This appears as a project connected procurement request for the procurement team. Items which are “2” indicate that they operate through available stock and are not connected to specific project. This project contains both “1” and “2” items. These are based on predefined criteria.

Under “Individual/coll.” is section “ProdVersions”. When the routing is completed in CA01 it is placed in this section to connect it to the material master. This is done by using transaction MM02 and selecting view MRP 4, pressing “ProdVersions” and creating a production version for that item as seen in Figure 16. This is done for all assemblies and in-house own manufacturing components.

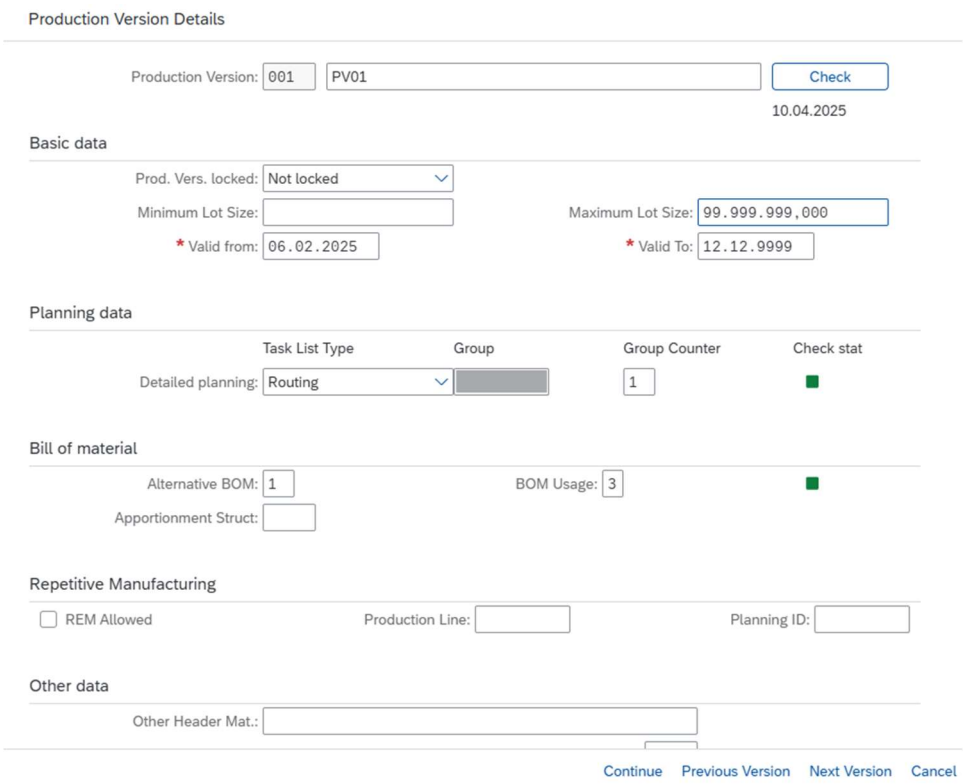

Figure 16. Production Version details in SAP – Connecting routing to material master

The production version, routing, group, group counter and BOM are first entered. After these are entered, “Check” button in the upper right corner is clicked to identify any errors. When

no errors are found, the “Check stat.” boxes turn green, as seen in the figure above. Once this step is completed, “Continue” button is clicked, and the changes to the material can be saved.

At this point, the routing is connected to the material. This process is repeated for each assembly and in-house manufactured products. To ensure that everything is correct and the BOM has been successfully sent to SAP, a custom business add-in is used. This application displays the BOM for the top-level assembly, along with material descriptions for subcomponents, quantities, units, document status, purchase group, procurement type and other relevant details. Once this has been checked, the next phase of this process begins: creating a project and placing the main assemblies in the Project Builder (CJ20N) in SAP.

4.3 Creating a project in Project Builder

A project is created using SAP Project System (PS) module using the Project Builder interface (CJ20N). Project Builder is used to structure the project efficiently, ensuring timely completion and the optimization of resources. Aspects of the project can be monitored through this way by creating Work Breakdown Structures (WBS), which divide the project into tasks or branches based on needs. The project is created by accessing Project Builder and choosing “create” option within the builder. This creates a project identification (ID) code which can be used in other modules to access needed information. During this the project type is selected from the options provided. The project type for this pilot project is “customer order”. During this phase the structure of the project is selected. This defines the scope of the project and links information such as company codes, plants as well as other organizational information to the project through WBS branches. After choosing a layout which is used to form the WBS structure, additional information can be added to the layout throughout the project such as work hours and schedules. Figure 17 in an example of what the branches can look like in project builder. These branches include important information such as the start and end date of the project which forms the outline of the schedule. These branches are customized based on the needs of the project and operational goals. Dependencies between activities can be defined which forms the proper sequence of tasks.

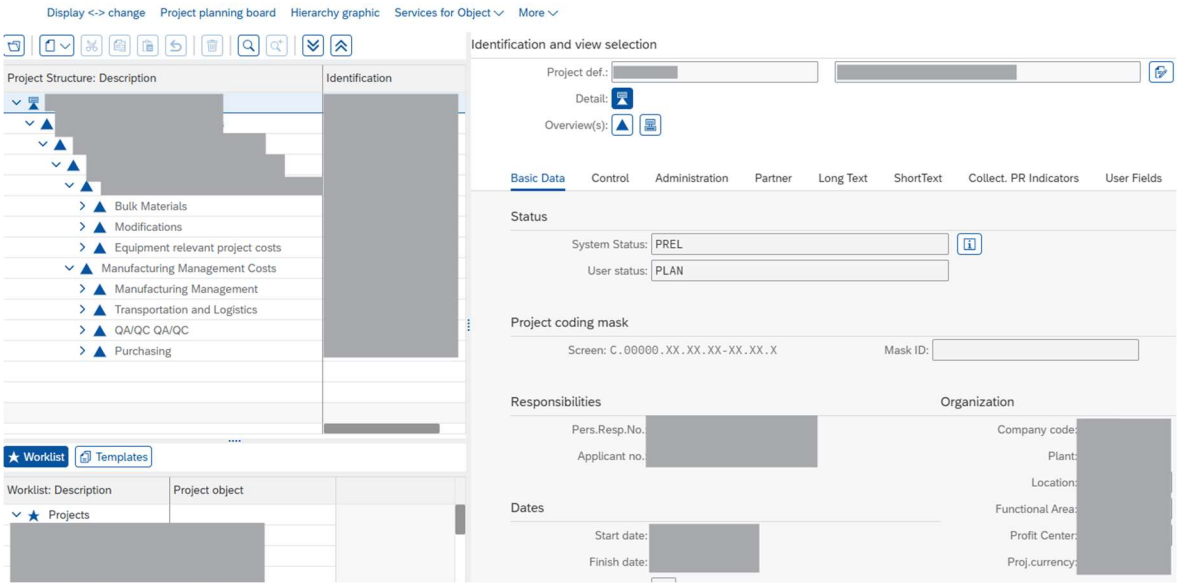

Figure 17. Project Builder – Project Structure for task management

This study consisted of two different ways of determining how the scheduling should be done in Project Builder. The scheduling was accessed through Project Builder as seen above by selecting a specific assembly through "Equipment relevant project costs" branch. The scheduling view is shown in Figure 18 below.

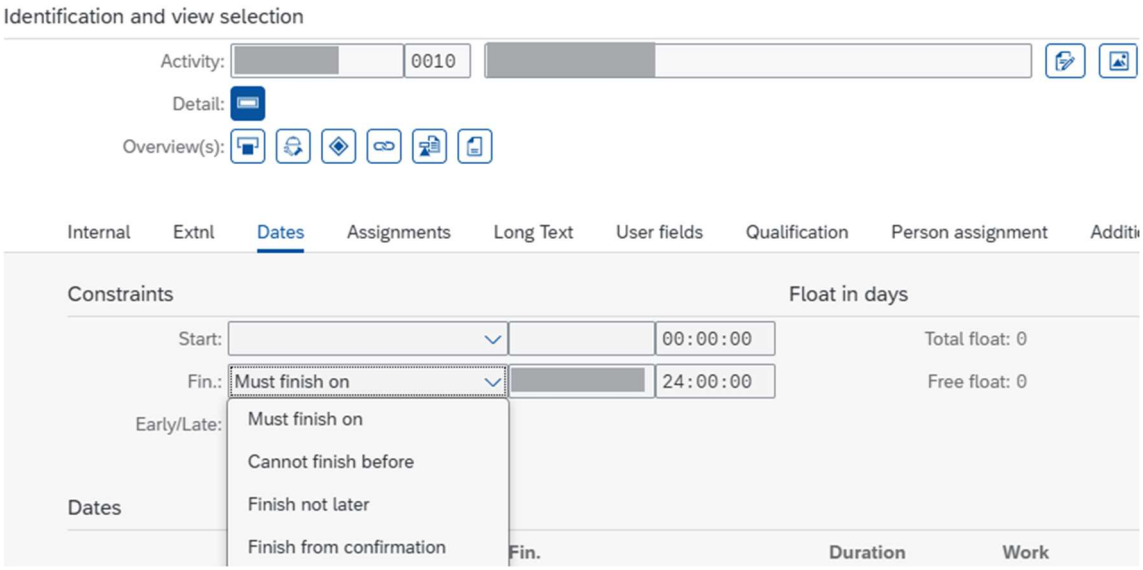

Figure 18. Setting a constraint for the project – Assembly 1: Must finish on date

As seen in the figure above, scheduling for this assembly was based on the “Must finish on” constraint. This method proved to be a reliable planning approach, as it resulted in planned orders being generated as intended. The “Must start on” constraint was also tested for assemblies but did not generate equally reliable planned orders. It often required more manual adjustments to align with the project schedule. This was due to assemblies having a good receipt time set in the material master.

The ”Must finish on” constraint also aligned better with project practises, where the focus is on completing the project by a specific deadline. Using the “Must start on” constraint on assemblies can lead to tasks finishing earlier than intended, potentially causing issues related to storage. In addition, this method makes it more difficult to control the project timeline accurately compared to the “Must finish on” constraint.

4.4 Production orders

Once structures are in the Project Builder, planned orders are formed. The planned orders can be viewed in “Monitor Production/Planner Orders” (transaction COOIS). This displays all planned orders within a plant which is determined before executing this transaction. Figure 19 is a representation of this, and the red outline indicates which information is necessary for the planner to see which planned orders are upcoming.

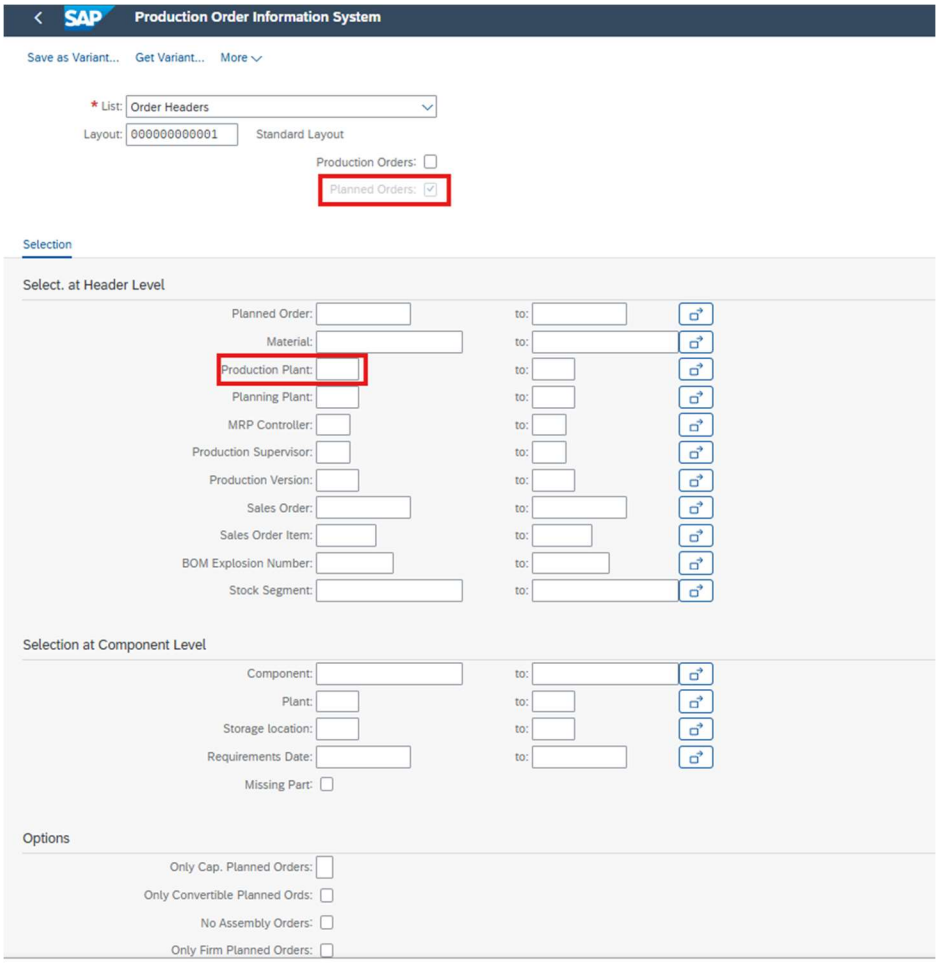

Figure 19. Production Order Information System in SAP (transaction COOIS)

Planned orders are then scheduled based on capacity and promised delivery dates. Routings which have been done beforehand specify how long each product takes to manufacture. Transaction COOIS can be used to monitor what orders are planned and should be scheduled but in addition to this COOIS can be used to monitor ongoing production orders.

Production orders for this project are listed in Table 3. These production orders are fabricated for this study and the actual production orders used in this project are concealed. For confidentiality reasons, only the first OCM production order in the dataset (order 4000000005) is presented. The remaining orders and the quantities are excluded from this report to comply with internal data protection.

Table 3. Production orders for the pilot project

Assembly	Production Order
1	4000000001
2	4000000002
3	4000000003
4	4000000004
5	1000000002
Electrification	1000000001
OCM (Prod.Ords. connected to assemblies above)	4000000005 … *n*-1 orders

During this project two production orders were opened as standard production orders processed through stock and the rest were opened as project related manufacturing production orders. This was done to simulate how production order types may vary and how they affect the overall planning process.

Transaction MD4C was often used for monitoring and provided valuable information regarding the status of the project including procurement, production order dates and the goods receive status for all subcomponents. Table 4 represent item element status for items which were monitored throughout the planning process to gain information regarding the procurement starts of components and to see if items arrive on time for manufacturing.

Table 4. SAP Multilevel Order Report – Item receipt element status

Receipt Element	Description
PrdOrd	Production order
PldOrd	Planned order
Stock	Item available in stock / goods receipt done
ProjSt	Item available in stock reserved for project in question and goods receipt done
POitem	purchase order which is not confirmed yet
ShpgNt	Confirmed Shipping purchase order

Receipt elements listed above were used to track the progress of procurement and confirmations. This was used to monitor if suppliers were able to confirm items as requested. The “PldOrd” status indicates that this order has yet to opened as a production order.

Whereas the “PrdOrd” indicates production orders which in this instance are top level assemblies or OCM items set as procurement type “E” in the material data. Stock and “ProjSt” indicate which items have arrived and GR has been done. These items are available for picking have arrived as expected. “POitem” suggests that this item has been purchased and “ShpgNt” indicates that this purchase has been confirmed. Next to these elements dates are shown. This indicates when production orders are set to begin, when components are arriving and if any components are arriving later than expected. These elements and dates are used to monitor if schedules need to be adjusted and if production dates align with components arriving to the plant.

4.5 Cross-functional coordination

The cross-functional coordination within teams was crucial to the successful implementation of the pilot project. The coordination within teams during this project is presented in Figure 20. This is used to show how each phase is linked. Structures are released by engineers which are then handled within the production planning team. The new way of planning project effects production planning and the phases after that.

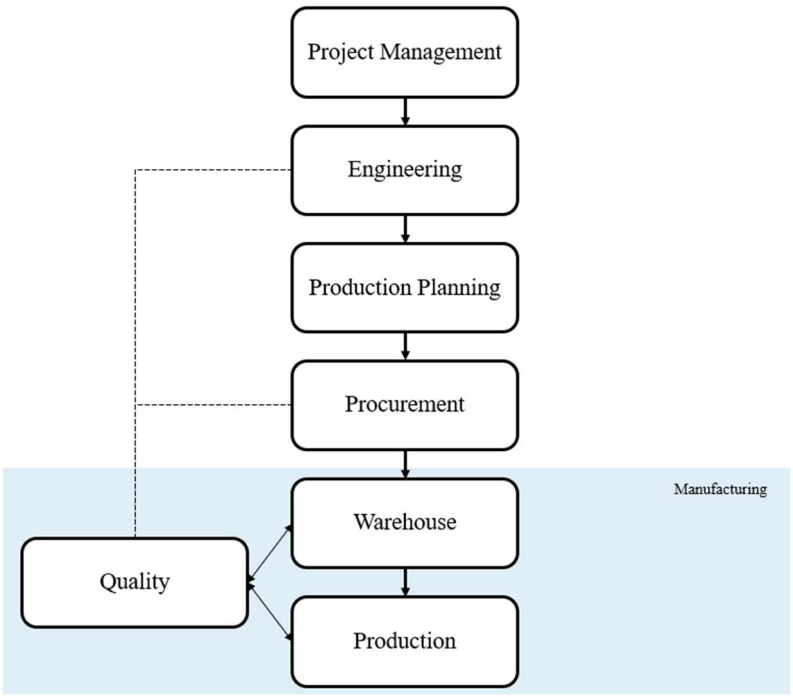

Figure 20. Cross function coordination during the pilot project

After the planning, procurement tasks are started. After procurement is monitoring of the project and gathering information regarding project schedules. Closer to assemblies these plans are then confirmed. When items arrive warehouse personnel perform good receipt tasks and place items according to predetermined locations where they are available for picking. After the goods receipt is done for all components and OCM items are available, assemblies may begin. It should be noted that quality is closely monitored throughout this process.

5 Results and observations

The results facilitate a deeper understanding of the project's potential, demonstrating the effectiveness and potential of production-order based planning in SAP. As a result, the project validates the new approach used to plan and schedule a pilot project and additionally provided valuable insight for scaling up, using this method of planning on projects in the future. However, it should be stated that the results of this pilot project only accounts for one project which may not fully account for all variables related to the planning phase. While the project provides valuable insight it additionally provides insight into areas which need further testing.

The results indicate major advancements in the methods for visually and cohesively tracking production orders scheduled in different phases of production. To achieve this, production orders should be executed accurately assigning materials with valid routings consisting of precise working hours for each phase from picking to production and packing. Each phase accounts for the estimated time for each task. While creating routings, each assembly and item should be analysed separately considering the measurements and materials used.

Structure handling in the PLM system

Minimal changes were observed during structure handling during the pilot project. The only notable difference involved reference points in the PLM system, which were deemed unnecessary. This had a minor effect on simplifying structure handling, but the impact was negligible. No other deviations were identified or expected.

Routing results

In the routing phase of this study included creating routings with operation sequences for the assemblies. The routings mainly consisted of material picking, assembly and packing for the assemblies. Routings for OCM are not identified during this study due to confidentiality reasons.

The results regarding routings can be assessed once actual hours are reported. This can be reviewed further after the project comes to an end. The routings can be changed accordingly, if necessary, once the actual hours are compared to the hours estimated during this project. Routing hours which differ significantly can influence cost fluctuations of estimated costs compared to actual costs which should be considered. With more deviations regarding the routings during projects, the larger the fluctuations may be.

Work centres and capacity planning

Work centres' capacity should be maintained and updated accordingly to equate actual capacity. It was encountered during the planning phase when production orders were released for production that the work centre capacities did not contain current information. This provided with an error message indicating that specific order could not be released due to capacity constraints. After investigating and consulting it was noted that this error message did not indicate an actual scenario, and the error message could be disregarded. This was bypassed by using an infinite scheduling approach for this one instance.

To obtain reliable data regarding the capacity, these should be updated and closely monitored. If all production is shifted towards a production order-based manufacturing, work centre and capacity planning should be current. This error indicates that this specific work centre's capacity is full, and the schedule should be shifted or capacity increased.

Scheduling in Project Builder

This section did not provide with major advancements since this method of using Project Builder and WBS is currently implemented. The major difference included with only entering assembly item codes and scheduling with "must finish on" constraint. This provided with accurate planned order start dates which are calculated based on definite routing times.

Production Orders

A significant advancement in the pilot project was creating production orders for assemblies – an approach not previously implemented on project-based planning at this specific plant.

Results indicate that the forming of planned orders went as expected. Planned orders were generated according to routing and scheduling data which was predetermined in Project Builder. These planned orders accurately represented the production timeline and production orders could be opened based on the planned dates in SAP.

An issue which has been encountered previously in projects was related to planned material requirements going to procurement view before these were opened as production orders. This was apparent in situations where a planned order could not be opened for external reasons such as waiting on costing for the material during this pilot project. This was not a substantial aspect of this project since the planned order dates were as expected based on the scheduling done in Project Builder and material data. This is an aspect which should be taken into consideration if further projects are executed using this method. This can cause human errors while purchasing items which have not been scheduled by opening the production order and verifying the dates. Issues related to this include that procurement may purchase items based on planned material requirements and the required delivery date for the material for vendor can be set based on wrong inputs. This issue is not dependant on this project but can increase the risk of this if all planning is done with production orders.

It was noticed that scheduling the assembly through “must finish on” was more efficient in this case and the planned order schedules were closer to reality. Figure 21 represent how the system scheduled an assembly backwards from the designated finish date aligning the production order timeline accordingly.

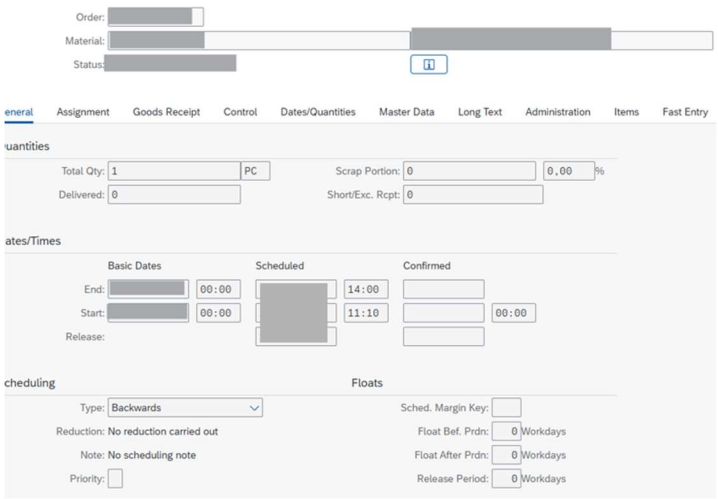

Figure 21. Display production order – Assembly 1: Backwards scheduling

In Figure 21 the scheduling type is set as backwards where the scheduling is done based on when this production order should be completed. The start date is determined based on the routing behind the material for which the production order is opened for. When opening a planned order, the execution dates suggested in section “Dates/Time” was based on the scheduling done in Project Builder (CJ20N). When the scheduling was done based on “must finish on” in Project Builder the suggested start and end dates for the production orders proved to be more reliable. This was due to the material data behind the assembly items. This can be useful in instances where planned orders cannot be opened immediately due to external reasons, but procurement must start. It should be noted that this method is not recommended and can cause issues such as materials arriving according to the planned production date if the date is modified when opening the production order.

When creating the material data for each item most data which is entered is constant and applies to many situations. During this project the data entered for each item was similar with minor changes. An example of this was having the same number of days for goods receipt processing. This was used on assemblies as well but looking back, it was not necessary, and a smaller amount of time would have been adequate. This was used during one assembly, and it was noted that scheduling using “must start on” in Project Builder worked so that the planned order was formed representing accurate times.

PP/DS implementation

The use of PP/DS was only done at a theoretical level due to this specific plant not having access. However, theoretical examination and consultation with an SAP professional suggest that PP/DS offers potential benefits. It can be concluded that further research regarding PP/DS implementation should be considered. The theoretical observations indicated that this can be used as a tool. Future projects should test the applicability and performance focusing on errors in routings which may led to inconsistent schedules in PP/DS.

Cross functional coordination

No major impacts were observed related to project management, engineering or procurement during the pilot when compared to previous planning methods. The procurement phase was

closely monitored throughout the process and the procurement specialist in charge of this project was consulted often. As a result, not major changes were observed.

However, an issue was identified in procurement where planned delivery dates were set in the material data as longer than the actual lead time of the project. It was discovered that this was caused by having long planned delivery times behind the material data. This data can be found in MM01/MM02 MRP 2 view “planned delivery time”. Results indicated that if materials did not have up to date or excessive lead times procurement requests would go further than anticipated. This can cause projects schedules to extend due to materials arriving after they are needed. This issue is not dependent to this pilot project and can arise in projects planned the current way. This was monitored with production orders through MD4C “Multilevel Order Report”.

Monitoring

Results provided insight into the monitoring of production orders in project-based planning. Monitoring tools used included transaction COOIS where planned and ongoing orders could be monitored. Additional tools identified during the project included using MD4C transaction where the project status could be monitored by entering the project number created for this project or individual production numbers by modifying the template and adding section “system status” to the top bar. This was used to see which production orders were released as well as the status of the project procurement.

Operational level and production order confirmations

Advancements identified included releasing production orders in SAP before picking could commence. The releasing of production orders was done through transaction CO02. The releasing of production orders can be done when availability checks have been made and all components required are available for manufacturing. In addition to availability checks, capacity planning must be available to execute the production orders as intended. When the order is released, the order printing is done for the operational level personnel including the material list which indicates which components are needed for the specific order.

The picking of materials for production was done differently compared to the current way of executing projects. This change was related to a different method of confirming steps in SAP. This new method is currently implemented on smaller projects and did not affect the picking in a major way.

The stock operators were consulted regarding shifting to one standardized way of executing picking. It was noted that this new method was preferred and made the process more streamlined by only having one method of conducting the picking phase. Currently the picking is done using two method and this project proposed a new cohesive way of executing planning which affects other production phases simultaneously.

A key enhancement involved the possibility of real-time confirmation of operations, enabling personnel to confirm task completion directly in SAP, thus supporting real-time tracking of project progress. This was not fully implemented during this project, but monitoring was executed as needed but the possibility of this implementation was found as a result.

Items available for both, small batch orders and projects

Some components used in this project were classified as phantom items with procurement type “E50” to avoid unnecessary production orders for phases which did not need to be completed individually and could be completed during the main assembly. If these items set as phantom were to be ordered individually, their material master must be temporarily changed to procurement type “E”, introducing a risk for human error. Although this posed no significant issues in the pilot, it may affect larger projects.

Overview of results

Advantages in transitioning to production-order-based manufacturing allowed for improved real-time monitoring, enhanced traceability, and better integration with capacity planning and MRP functionalities. It facilitated accurate tracking of materials, operations, and finished goods. Moreover, it supported efficient resource utilization and enabled advanced reporting and analytics.

6 Discussion

This chapter goes in depth regarding the results observed during the pilot project. These results are compared to previous studies and the literature review conducted in the initial section of this study. Results examined include overall efficiency, integration achieved between planning and execution. Additionally, the implementation of production-order based manufacturing method offered improvements in task allocation accuracy, scheduling reliability and collaboration between teams, supporting a cohesive workflow which aligned with the project targets.

6.1 Results discussion

This pilot project was conducted as a case study where engineering-to-order (ETO) method and make-to-order (MTO) approaches were used. ETO was mainly used however subassemblies consisted of MTO approaches. The applicability of time-phased planning such as material requirements planning (MRP) provided effective MTO environments, consistent with Tenhiälä (2011). During the pilot project, MRP allowed for production activities to be tied to demand rather than forecasts. This minimized excess inventory and provided a better control of material flow. Additionally, make-to-stock (MTS) method can be utilized during projects but was not evident during this project. In MTS approaches it was found that JIT methods were more suitable. These approaches benefitted from lean, demand driven scheduling and minimal inventory levels which JIT supports.

The ETO aspects of this project provided a dynamic production process. Carvalho et al. (2015) highlighted the physical and nonphysical stages in ETO production. The nonphysical stages included engineering, planning and customization process during engineering phases. These presented complexity in scheduling due to the customised structures and close coordination between teams. This section of the pilot project empathized the importance of process optimization and early planning.

Aggregate production planning (APP) is used in medium-term projects where the project timeline is between 3 to 18 months. This planning method was found to be a critical role in

medium-term strategy especially in aligning workforce capacity, inventory and production rates. This was supported by Jamania et al. (2018) and Carvalho et al. (2015).

This project combined an approach utilizing MRP and JIT frameworks to enhance production efficiency and material flow. MRP was used during the pilot project to manage the planning of material requirements, ensuring that procurement requests were generated based on the production orders and demand. This allowed for precise scheduling and the procurement of components at a timely manner. In addition to MRP, JIT method was used at an operational level to minimize excess inventory and ensure components arrived when needed for assembly. This was done by maintaining the material data and determining an appropriate amount of time for good receipts. This method enables the reduction of storage costs. By applying these methods, the project achieved a balanced production flow, reduced material holding times and improved coordination between planning, procurement and manufacturing activities.

Lean manufacturing (LM) principles were integrated during the project to improve efficiency and eliminating non-value activities. This was aligned with creating a consistent and manageable schedule. Pinto et al. (2018) highlighted five core principles related to JIT where information flow, shared responsibility and continuous coordination were crucian in maintaining effective manufacturing. This was used throughout the pilot project where information flow was highlighted during phases which had not been implemented on project previously. This included close communication with team leaders and operational level personnel. An example of this was during the picking phase where this was done differently compared to previous projects. Clear communication was needed to monitor the process and inform about changes such as releasing production orders for personnel to be able to begin picking. Coordination was needed to ensure all steps were accounted for and executed as needed.

The integration of PP module in projects linked to production orders provided a structured way to track production status and align timelines with planning outputs. This was done through managing production order dates and the release dates of orders. These allowed for production schedule adjustments and adjusted them if needed in response to order changes or capacity constraints. Other benefits identified which are linked to the PP module include the possibility of adding new monitoring and scheduling tools such as the PP/DS.

The pilot project demonstrated that combining MRP and LM frameworks with SAP planning in PP module provided efficient and customer-focused production systems. However, these depend on which production application is in question, MTO, MTS or ETO and tools should be aligned accordingly. Production orders were the main focus of the project, and they served as instructions for executing specific tasks and were used for tracking, managing material requirements and ensuring scheduling alignment. This provided details such as release dates, due dates, operations, capacity loads and material reservations. This enables for a structured planning process. The release and due dates were a key aspect in capacity levelling.

Effects which were identified during the pilot project regarding production planning unification to one standardized way provided valuable results related to cohesive coordination within team. The results included reduction in production bottlenecks and communication between teams, all of which contributed to increased efficiency.

It was noticed that production efficiency could be measured by analysing key metrics related to the effectiveness of the production process. The following methods could be implemented to gain more insight regarding production efficiency: productivity ratio, resource utilization such as labour, machinery, material rotation, the downtime of machines and analysing cost fluctuations related to production order-based manufacturing.

6.2 Reliability and validity

Reliability and validity are crucial to ensure that the findings in this research are both consistent and current. These concepts are used to evaluate the robustness of the research structure and credibility of the findings. To ensure reliability a systematic approach to gather data was followed throughout the pilot project utilizing standardised procedures in production planning. This was done to ensure that results were not influenced by external variability. Other factors in maintaining reliability were including teamwork and close monitoring with professionals to observe and evaluate specific steps in the planning and production phases. Throughout the project professionals in different areas such as procurement, quality, development, production and team leading were consulted to attain data throughout. To conclude, both reliability and validity had a major role throughout this project and the careful consideration of these enabled consistent, repeatable results while also highlighting areas which need further refinement or analysis.

6.3 Future research scopes and potential developments

Due to growing demand, optimized production processes, streamlined workflows and enhanced material management are crucial in maintaining operational efficiency. Future research and development in production planning will address new challenges in areas such as resource optimization and the integration of advanced systems for more reliable forecasting, demand planning and real time monitoring. This subchapter covers the potential developments in this area of study as well as potential developments regarding the pilot project and the company in question.

Future research scopes should cover PP implementation on a broader basis to identify best practices and measurable outcomes. Particularly, the scalability of PP frameworks should be identified and this implemented on larger projects with more variables. Long-term effects should be addressed and followed to gain more insight on this method. The traceability and execution of a large number of production orders simultaneously within one plant should be studied.

It was noted that recent research on this topic was hard to come by and therefor results could not be compared to its full potential. This was identified as a research gap for potential future studies.

The potential of integrating PP/DS within this plant should be assessed further due to limitations during this pilot project. The most limiting aspect of this section of the project is that PP/DS has not been implemented in this plant which means that the planning resources on SAP were not accessible within this plant.

Implementing this production planning method, through the PP module would involve in further developments regarding monitoring production orders. A new standardised way of following up and monitoring the phases of these production orders should be investigated. In addition, the communication between operational level personnel and team leaders regarding which production orders should be executed at each phase and how this is monitored should be discussed. The releasing of production orders for picking should be done in a standardized way which needs to be taken into practice.

Future studies could be done in phases where the number or projects planned through the PP module could be done in a controlled way. This would able close monitoring and

investigating how a growing number of production orders would affect production and monitoring. Improvements would include shifting towards a more standardized and cohesive way of executing operational phases such as executing different operations such as material picking for projects and production phase confirmations.

Other potential research topics which are not limited to this project include resource optimization, material allocation and work area standardisation. An example of this includes material circulation in warehouse, quality monitoring during this and improved material management – reducing material shortages.

As observed during this study, the PP module supports improved forecast and demand planning. The utilization of this is a topic in which more results could be obtained. Based on the need for monitoring tools within this plant would indicate the need for training to implement these methods and clear communication between teams to ensure that each personnel are equipped for this shift. In addition, developing a clear structured data migration strategy with testing phases to ensure data integrity should be assessed.

7 Conclusions

This study examines the transition to production order-based manufacturing where larger assemblies are executed by production orders in SAP. The implementation of this method for project-related production presents a strategic opportunity to unify and streamline the production planning within the company for which this study is conducted for. The focus of this study demonstrates the feasibility of managing larger-scale assemblies within the Production Planning (PP) module by integrating project-related tasks into a standardized planning structure. This pilot project showcased the ability to coordinate production phases effectively by utilizing SAP functionalities including material data, routings, work centres, and real-time order confirmations.

Unifying all production planning which is currently executed using two different methods within the company in question presents significant advantages for operational efficiency and strategic project execution. This method which was used during this case study is used on smaller scale manufacturing such as spare part manufacturing within this specific plant for which this study is done for. By merging planning processes previously split between PS and PP modules the risk of miscommunication can be minimized and the streamline coordination between different teams by utilizing one process which applies to all manufacturing. The integration provides real-time monitoring and simplifies processes by using one standard method. This involves planning production-related tasks through a consistent process. This supports a clearer communication between teams.

Key findings from the practical phase of this study include successful scheduling and creation of planned orders for assemblies. Advantages regarding using “must finish on” in Project Builder enables for more accurate planning and procurement requests while using material data inputs used previously. While risks were identified such as potential discrepancies in material requirements and risks linked to phantom items, the risks were identified to be manageable and provided valuable insight into areas for future improvement.

Primary changes identified using this method included creating routings for top level assemblies and having the costing done for them. This method involves ensuring that work centres are updated to the current capacity on SAP. Additionally, different production phases were formed into a more cohesive way following a standardised way of executing planning

in spare part manufacturing and OCM. This influences different production phases such as picking and assembly work. It was identified that the production order confirmations could be done in real-time which could allow for real time monitoring of which production steps are completed for each project.

The study explores the key factors impacting the accuracy and efficiency of production scheduling in SAP S/4HANA PP-module, the effects of unifying these methods and the role of production-based manufacturing in cross-functional coordination related to the research questions. Findings indicate that unified planning approaches enhanced operations by streamlining tasks and enabling more consistent decision-making. This proved to have a major impact at an operational level. Cross-functional coordination was proved to be more consistent, and no major changes were identified in the initial part of the project. Changes were noted during planning and at the operational level.

This study highlights the benefits of transitioning to a unified production planning model in SAP PP. Benefits include enacting reporting accuracy, reduce complexity, and foster a more cohesive workflow. This study was limited to one project which the results are based on, the results indicate a clear potential for broader implementation which should be examined further.

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Appendix 1. Interfaces used during pilot project's production planning in SAP

Transaction	Description	Input	Output
CO02	Manage Production Orders	Production order	Production schedule and component changes
CO03	Display Production Order	Production order	Monitoring
CA01	Create Routing	Material data, work centers, operations, work hours	Routing number, work center assignment, production orders
CA02	Change Routing	Item code	Operation sequencing changes and durations
CA03	Display Routing	Item code	Monitoring
CJ20N	Project Builder	Project name, ID, type, timeline, WBS elements, network and activities, materials, costing	Project Structure, network structure, resource allocation
COOIS	Monitor Production / Planned Orders	Production or planned order	Task list of planned orders or monitoring of production orders
MD01N	MRP live	Material Master, BOM, work center, routing	Planned Orders, procurement proposals, material availability
MD04	Monitor Stock / Requirements List	Item code	Item availability and stock availability
MD4C	Multilevel Order Report	Project number or item code	Monitoring of procurement statuses and production schedule
MM01	Create Material Master	Material type, description, unit of measure, relevant information	Material master data such as: -Basic data -Purchasing data -Inventory data

		regarding material properties	Integration with other modules
MM02	Change Material Master	Material code	Changes to material master
MM03	Display Material Master	Material code	Monitoring